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15 August 1983

NAHBE M151 RETROFIT EVALUATION

Final Report To:
Director, Power Program
Material Science Division
Office of Naval Research
Washington, D. C.

Contract No.
N00014-81-M-0058

75 Pages, Unclassified, Distribution Unlimited

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SONEX 838151	2. GOVT ACCESSION NO. AD-A133475	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MAYBE M151 Retrofit Evaluation		5. TYPE OF REPORT & PERIOD COVERED Final - 1 July 81-30 June 83
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. A. Pouring, C. C. Failla		8. CONTRACT OR GRANT NUMBER(s) N00014-81-M-0058
9. PERFORMING ORGANIZATION NAME AND ADDRESS Sonex Research, Inc. 300 Chinquapin Round Road Annapolis, MD 21401		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Director, Power Program Material Science Division, Office of Naval Res. Arlington, VA 22217		12. REPORT DATE 15 August 1983
		13. NUMBER OF PAGES 75
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Internal combustion engines
M151 - ¼ ton utility truck (Jeep)
Naval Academy Heat Balanced Engine (NAHBE)
Combustion radicals
Multi-fuel engine, Engine emissions, Fuel economy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

NAHBE (Naval Academy Heat Balanced Engine) state of the art technology was applied to a standard military four cylinder M-151-1/4 Ton Utility Truck (Jeep) to demonstrate retrofitted versus standard engine performance in waterbrake and chassis dynamometers as well as on the road.

Chassis dyno results showed a maximum possible retrofit improvement in miles per gallon of 21.3% at 55 mph and 35.4% at 30 mph. Waterbrake dyno results show higher improvements at low throttle settings indicating that

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further improvement on the road is possible by proper coordination of fuel, air and spark timing.

NAHBE exhaust gas temperatures are on the order of 200°F lower for equal throttle settings and RPM with maximum temperatures equal to or below the lowest standard engine temperatures. The spread in temperature between max-min at a given speed is reduced by a factor of 3-4.

Waterbrake dyno emission levels of CO, HC are reduced significantly (NO_x not available at the time); chassis dyno emissions for steady state and transient conditions include NO_x. No EGR, air pump or catalytic converter were used.

Much flatter torque curves were observed at all throttle settings with appreciable increases noted at part throttle shift point RPM.

Recommendations are made for further improvements and the development of a multi-fuel engine utilizing low compression ratio (<8) autoignition by radicals.

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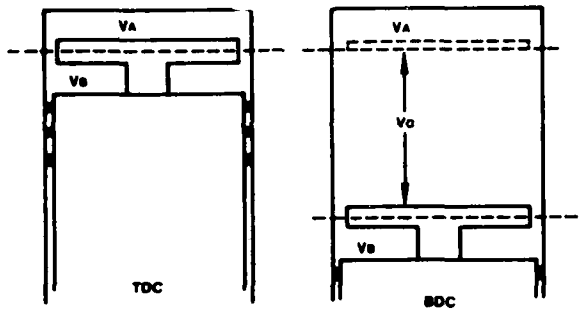
II. INTRODUCTION AND OBJECTIVES

It was proposed originally in an unsolicited proposal to ONR dated 1 May 1981 that the state of the art of the technology described in Reference 1 be applied to retrofitting an M-151-1/4 Ton Utility Truck (Jeep). Thus, a brief review of recent research reflecting the state of the art is presented here as well as an update on this company.

From the point of view of both theory and experiment in single cylinder engines, References 1-4 reflect the latest advances. Reference 1 summarizes the influence of geometries involved in piston design, secondary air manifolding and gives, as well, a comparison of a standard engine using the same technique of manifolding.

Since we are dealing with a new technology a quick review of the associated terminology is in order (from Reference 1). Two basic differences are involved in this engine concept. First, a cap is used on top of the piston to create a divided chamber in the cylinder. The upper chamber, V_A Figure II-1, is the combustion chamber, while the lower chamber, V_B, is the "balancing" chamber or air reservoir. The ratio V_B/V_A is defined as eta, the balancing ratio. The total clearance volume $V_C = V_A + V_B$ is used in computing compression ratio. A gap exists between the cap and the cylinder wall.

The objective is to create an axially stratified charge in the cylinder, with a lean mixture at the bottom, rich at the top, such that on compression a very lean (ideally air only) charge is forced into the balancing volume; a rich composition remaining in the combustion chamber. It is shown in Reference 4 how compression waves formed by the combustion front penetrate



V_A = VOLUME ABOVE CAP (COMBUSTION CHAMBER) @ TDC
V_B = VOLUME BELOW CAP (BALANCING CHAMBER)
$V_C = V_A + V_B$, CLEARANCE VOLUME
V_D = DISPLACEMENT
$r = (V_D + V_C)/V_C$, COMPRESSION RATIO

General Terminology for Heat Balanced Engine

Figure II-1

the balancing chamber, compress the medium within, and pump mass from the balancing chamber to the combustion chamber. It is this pumping action which prolongs the combustion process allowing control over both pressure and temperature in the cylinder.

In addition to the time dependent combustion inherent in this technology, internal heat regeneration is known to play an important role in improving performance of the engine. It is shown in Reference 2 that at low compression ($r \sim 5$-6), compression ignition operation with various fuels is possible. The energy for ignition must come by heat transfer or radicals[(6)]. Reference 3 is the first step in explaining the role of regeneration in this engine; under study at present is the effect of regeneration in a dual or combined cycle and the influence of precombustion radicals.

The second difference involved here is associated with the method of attaining axial stratification or separation of the charge. Reference 1

explores several modes of attaining this with carburetted engines. The means selected of introducing secondary air into the intake manifold requires a feeder tube welded into the intake manifold allowing air alone into the region of each intake valve. Since the intake valve is open only a fraction of the time, a charge of air accumulates in the intake manifold to be followed by a richer than "normal" charge from the carburetor. Reference 1 shows how engine performance is affected by variation only of this secondary air parameter in figures 14-18.

Attaining control of secondary air in a vehicle is made possible by the technology described in Reference 5. A feedback control system regulates admission of secondary air by examining engine output continuously. Secondary air is thus controlled by an electronically controlled feedback air throttle.

The vehicle described in this report contains modified pistons, modified intake manifold, and a secondary air control system; minor modifications in carburetion were also made.

HBR was founded to develop into practical form the art described thus far. Because of default of the original financial backer, more than six months were lost in completing the work described here. However, the company was reorganized, renamed to Heat Balanced Research,* and refinanced. The company now has a machine shop, instrumented waterbrake dynamometer lab and instrumented chassis dynamometer. It holds an exclusive license on the secondary air control patents for use in HBR technology, has an agreement with Gulf Oil with regard to multifuel engine testing, and is currently negotiating with Eaton Corp. for manufacture of components. An agreement

*now Sonex Research

with AM General provided the vehicle in the report as well as testing before and after the modifications by Sonex.

Objectives:

To apply the technology outlined above to an M-151-1/4 Ton Utility Truck (Jeep) such that:

1) a pre-production prototype is produced which will improve overall fuel economy.
2) emissions are lowered to the point of meeting 1980 EPA standards with no EGR, no exhaust air pump and no catalytic converter.
3) the engine is insensitive to Octane number.
4) the design is retrofitable.

III. DESIGN PARAMETERS

1) General Approach, Piston

Two engines were converted to the heat balanced design; one a scrap engine completely rebuilt, and the second taken from the M-151 provided by AMG for this test. The purpose of using the scrap engine was to test design parameters, that is compression ratio (r) and balancing ratio (β). According to Reference 1 optimum results should be obtained at $r \cong 8$ and $\beta \cong 0.8$.

The first M-151 design gave $r \cong 7.5$ with the difference attributed to cumulative measurement error. Since 0.100 inches was already milled from the head, it was impractical to reduce the head volume further. A decision was made to reduce the balancing volume to compensate giving the final result of $r \cong 8.0$ and $\beta \cong 0.5$. The resulting composite piston is shown in Figure III-1.

Figure III-1

2) Intake Manifold

Reference 2 gives some details on the percentage of primary versus secondary air used at best power with several fuels and hence the design proportions on the intake manifold. From Reference 1, the percentage secondary air is seen to increase at best economy since best power is at an air/fuel (A/F) ratio A/F $\cong$ 16, while best economy is at A/F $\cong$ 20. Thus, at best power the primary/secondary (P/S) air flows should be $\cong$ 50/50 and at best economy P/S $\cong$ 40/60.

Intake manifolds were fabricated with these ratios, but output equal to the standard engine could not be obtained. It appeared that with the single barrel side-draft carburetor full advantage of the secondary air could not be taken as the throttle opening approached W.O.T.. The pressure drop through the secondary throttle was too large compared with the primary; this was confirmed by flow bench tests. This can be avoided by using a two barrel carburetor with dual port manifolds, a current practice by Sonex (BSFC = 0.378 lbs/BHP-HR has been attained in such a design).

As a compromise, the W.O.T. power was sacrificed to obtain good part throttle results and the secondary air size reduced to accommodate the part throttle range. The resulting manifold is shown in Figure III-2.

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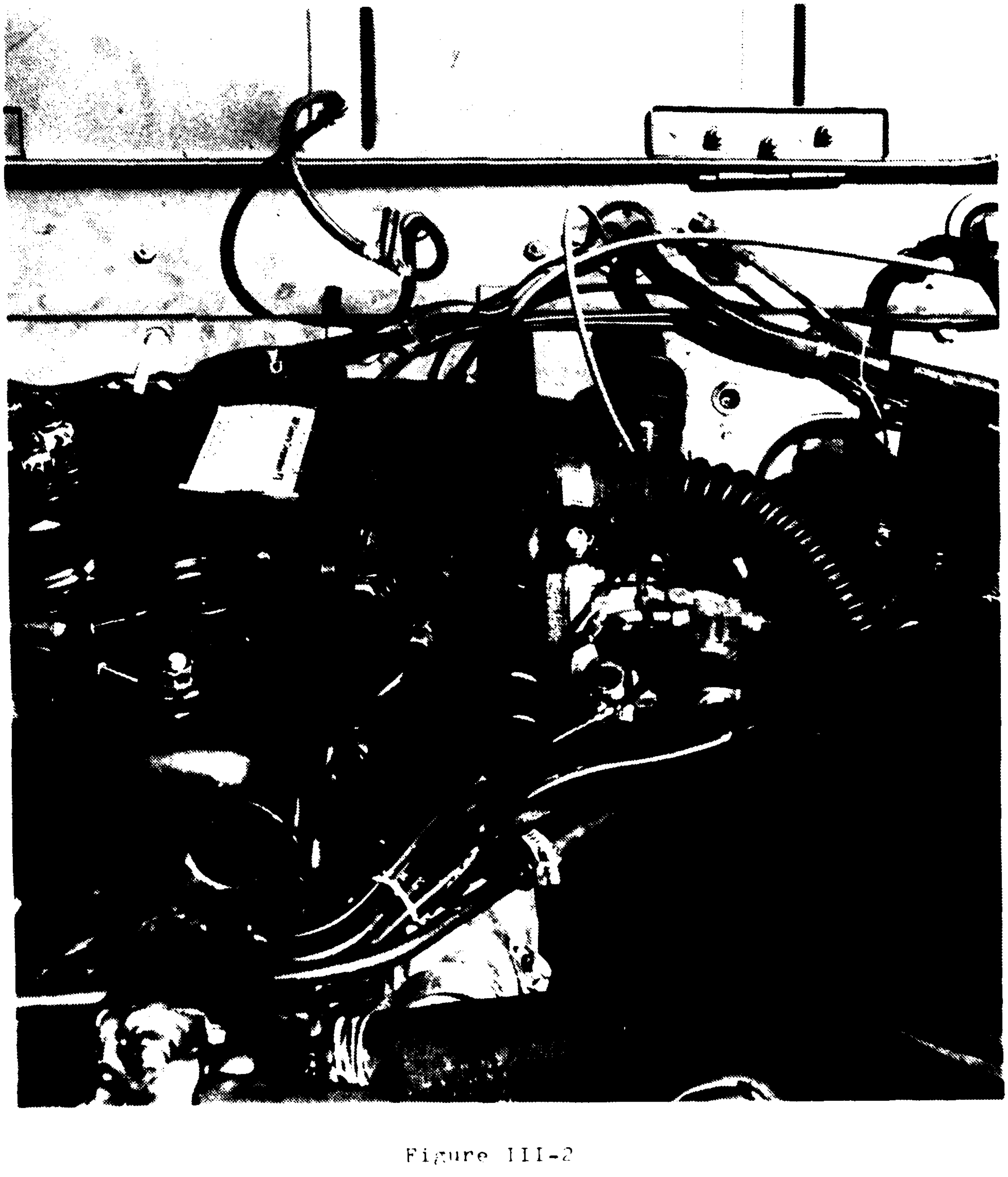

Figure III-2

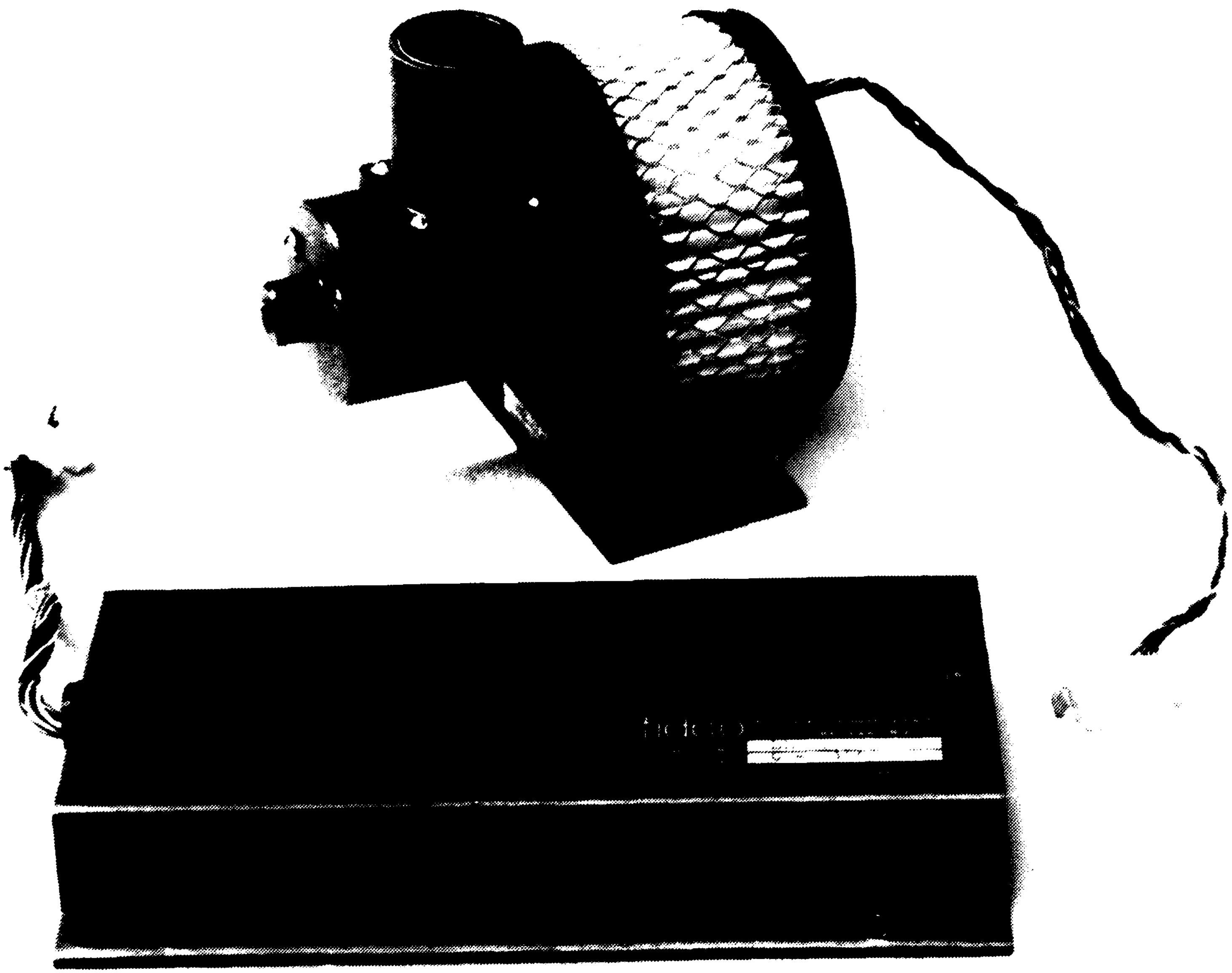

Figure III-3

3) Secondary Air Control

Using the adaptive lean limit control concept described in Reference 5, continual adjustment of the secondary air flow is possible, except, in this engine, for conditions approaching W.O.T.. A digital stepper motor, driven by appropriate circuitry, continually adjusts an air throttle valve at the entrance to the manifold secondary to give an optimal air fuel ratio. Several adjustments are possible to tune the speed of response, cut-off speed and A/F ratio. A view of the air throttle and electronics is seen in Figure III-3.

Test data are presented using both manual and electronic secondary air control. Torsional vibration feedback from the waterbrake dyno interferred with proper sensing of acceleration and deceleration of the engine crankshaft which is vital to FIDCO operation. This problem was not experienced on the chassis dyno.

4) Carburetor

Several variations in carburetor design were investigated. In an attempt to richen the low RPM operation, a boost venturi was added to the stock Facit-Zenith carburetor. Data in the waterbrake dyno are for the carburetor with boost venturi. Chassis dyno tests were conducted with and without boost venturi. Various combinations of idle jet tube, power valve tube and spring, and main fuel jet were investigated. The final configuration used a standard idle tube, no boost venturi, #32 main fuel jet, standard power valve-accelerator pump tube, standard power valve spring with washers to actuate at 4-5 inches of Hg.

Since the standard carburetor has no mechanical accelerator pump cold starting is often difficult. An aircraft engine primer was added to the carburetor by drilling out an existing brass plug and tapping for a 1/8" pipe nipple. Fuel supply was taken by adding a tee to the fuel recirculation fitting. The primer, located on the dash board, is manually actuated by the driver and is generally required only on the first start of the day.

5) Spark Timing

The number of variables involved in this engine concept is greater than for the standard engine making determination of the minimum advance for best torque difficult. An attempt was made, however, to optimize the spark electronically in the waterbrake dyno using a TRAC II, J & S Electronics, Garden Grove, California. These results together with variations possible with the existing system were considered in determining the best spark advance profile. The final settings were determined using stock springs and weights and a static advance of 17^{0} BTC.

6) Valve Timing

Valve overlap affects the intake manifold fuel/air composition. The objective here is to attain a separated charge or axially stratified charge first in the manifold, then in the cylinder. To lessen the influence of valve overlap on the intake manifold tests were conducted on optimum valve clearances with a stock camshaft. The influence was quite clear and final clearances (hot) adopted are given below.

7) Summary of Final Design Parameters*

Compression ratio	8.0:1
Balancing ratio	0.5
Piston	composite Heat Balanced Design
Intake manifold	stock with welded secondary air feed, .375 inch I.D.
Secondary air control	Electronic Lean Limit design by FIDCO/HBR
Carburetor	stock with #31 main fuel jet, stock idle tube, stock power valve tube, stock power valve spring plus 1/16" washer
Spark timing	stock springs and weights, 17^{o} BTC

Valve clearances

	Modified	Stock
Intake	0.025 inch	0.015 inch
Exhaust	0.020 inch	0.015 inch

* Used in Sonex testing prior to AMC testing.

IV. FABRICATION DETAILS

Techniques developed during the past year allow scaling of optimized piston design results from one engine to another. At present, however, finite element programs for thermal and stress analysis are not available. In their absence simple electrical analogs are used to determine approximate temperature distributions. Such techniques are not sufficient to design a piston entirely of aluminum that will last a reasonable time under operating conditions. Thus, the composite piston shown in Figure III-1 is used with a steel cap attached by machine screws to a forged aluminum base made to our specifications. A similar design under test has recently passed 12,000 miles on the road with no adverse affects.

All machining on the piston base and caps was done in the HBR machine shop. Final assembly of the engine and the final shave on the head (to a depth of 0.100") was done by experienced engine builders - Precision Engine Machine Co., Hyattsville, Maryland. All piston-rod assemblies were taken to the lightest assembly weight.

Unfortunately, the engine as received from AMG was bored to maximum tolerances. Special piston rings had to be used to satisfy maximum end gap tolerances with the pistons used. Since fitted rings were not available in the width normally used in the M-151, a narrower width was used with spacers. This fabrication compromise resulted in a long break-in time, and most of the waterbrake dyno testing was done with the engine not fully broken in as compression test readings continued to rise up to the time of chassis dyno testing. This feature may also shorten piston life and reduce the effective compression ratio.

Little machining was required other than drilling in modifying the intake manifold. Aluminum tubes were welded into the aluminum manifold with threads at the upper end to accept standard copper tubing fitting. The rest of the secondary air intake was made from copper fittings soldered together.

V. PERFORMANCE ANALYSIS

1) Test Equipment and Facilities:

a) Stuska Waterbrake Dynamometer, 400/800 HP

b) Clayton Chassis Dynamometer with inertial wheels

c) Fluidyne Fuel Flow meters (Model 1226 with digital readout)

d) Beckman CO/HC Infrared n-Hexane Emissions Analyzer (Model 590)

e) Thermo Electron Chemiluminescent NO/NO_x Analyzer

f) Linear Chart Recorder

g) Scott Calibration/Span gases

2) Waterbrake Dynamometer Tests of the NAHBE and Standard Engine

a) Index of Performance Curves (versus RPM)

Figure No.	Throttle Position	Engine	Curve
V-1	1/4	NAHBE & Standard M-151	Brake Horsepower (BHP), corrected
V-2	1/4		Brake Specific Fuel Consumption (BSFC), corrected
V-3	1/4		Carbon Monoxide, CO
V-4	1/4		Hydrocarbons, HC
V-5	1/2	NAHBE & Standard M-151	BHP, corrected
V-6	1/2		BSFC, corrected
V-7	1/2		CO
V-8	1/2		HC
V-9	3/4	NAHBE & Standard M-151	BHP, corrected
V-10	3/4		BSFC, corrected
V-11	3/4		CO
V-12	3/4		HC
V-13	WOT	NAHBE & Standard M-151	BHP, corrected
V-14	WOT		BSFC, corrected
V-15	WOT		CO
V-16	WOT		HC

Figure No.	Throttle Position	Engine	Curve
V-17	1/4, 1/2, 3/4, WOT	NAHBE	BHP, corrected
V-18	1/4, 1/2, 3/4, WOT	Standard M-151	BHP, corrected
V-19	WOT	NAHBE, Std. M-151. NAHBE-Holley Carburetor	BHP, corrected
V-20	1/4, 1/2, 3/4, WOT	NAHBE	BSFC, corrected
V-21	1/4, 1/2, 3/4, WOT	Standard M-151	BSFC, corrected
V-22	1/4, 1/2, 3/4, WOT	NAHBE	CO
V-23	1/4, 1/2, 3/4, WOT	Standard M-151	CO
V-24	1/4, 1/2, 3/4, WOT	NAHBE	HC
V-25	1/4, 1/2, 3/4, WOT	Standard M-151	HC
V-26	1/4, 1/2, 3/4, WOT	NAHBE	Exhaust Gas Temperature (EGT)
V-27	1/4, 1/2, 3/4, WOT	Standard M-151	EGT
V-28	1/4	NAHBE, Manual, Auto, Std. M-151	Torque ( )
V-29	1/2	NAHBE, Manual, Std. M-151	
V-30	3/4	NAHBE, Manual, Std. M-151	
V-31	WOT	NAHBE-best, NAHBE, Std. M-151	

K•E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO.

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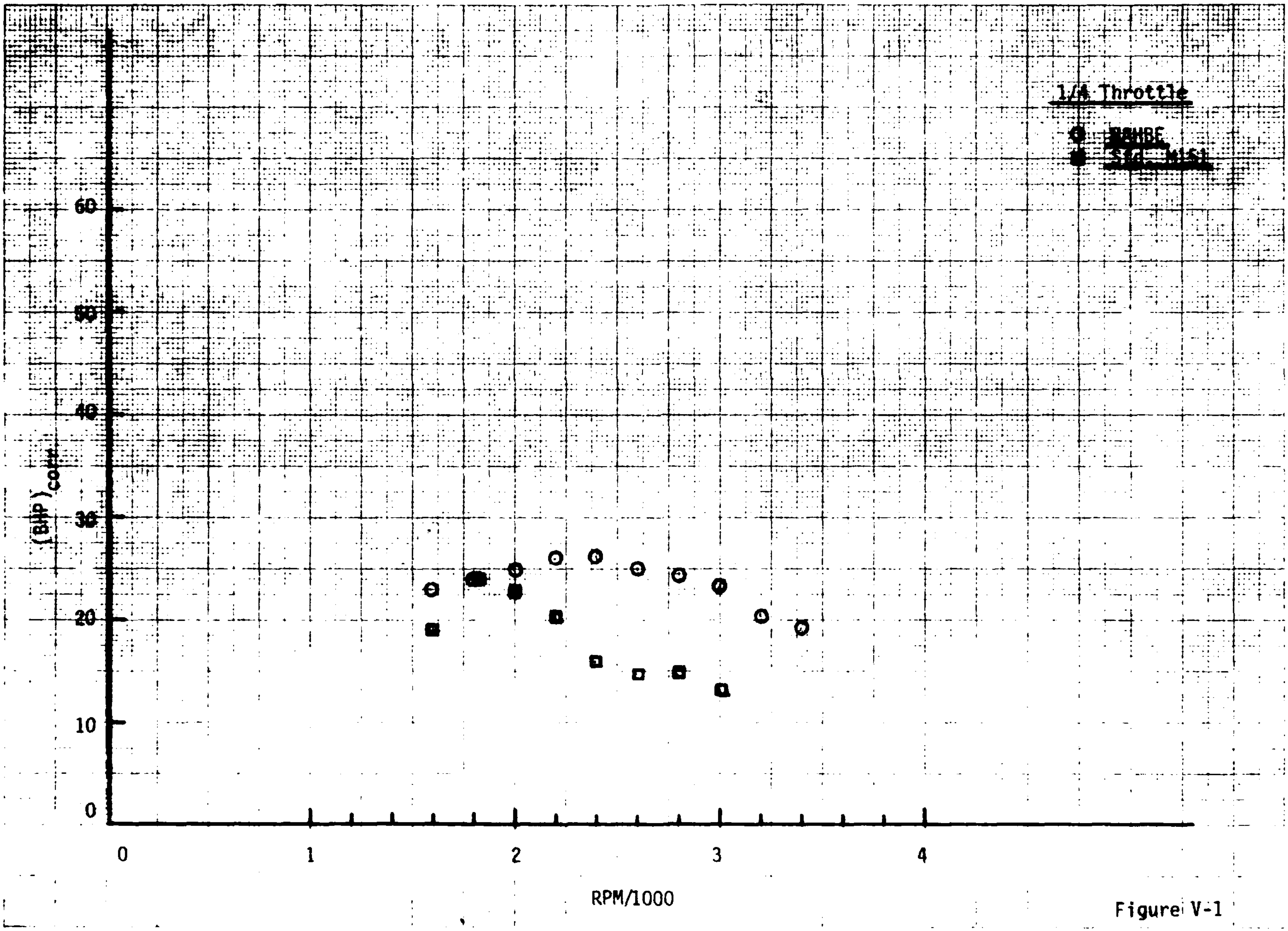


Figure V-1

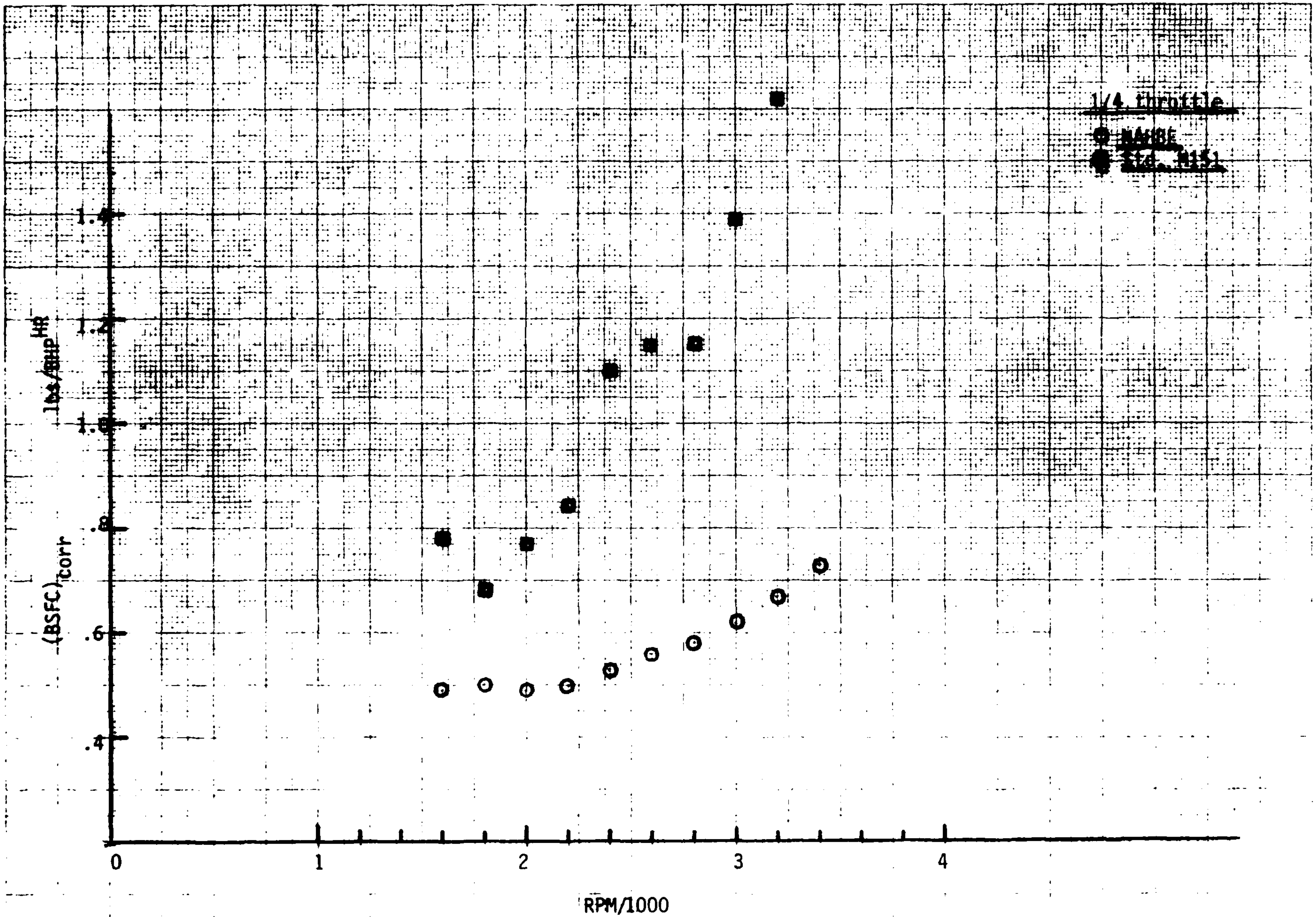

1/4 throttle
Std. M151
(BSFC)$_{corr}$ lbs/BHP$_{HR}$
1.4
1.2
1.0
.8
.6
.4
0
1
2
3
4
RPM/1000

Figure V-2

K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO.

46 1513

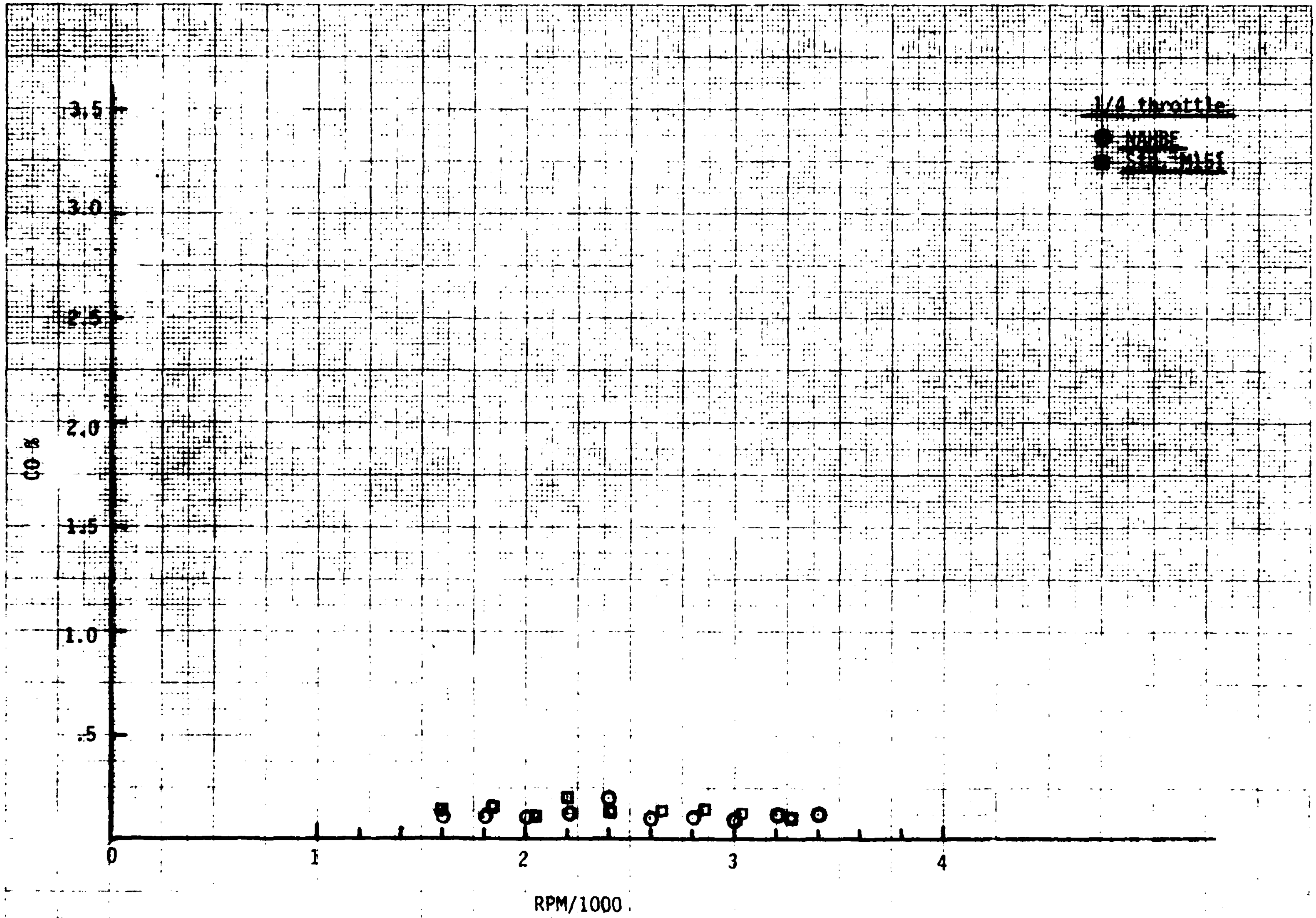


Figure V-3

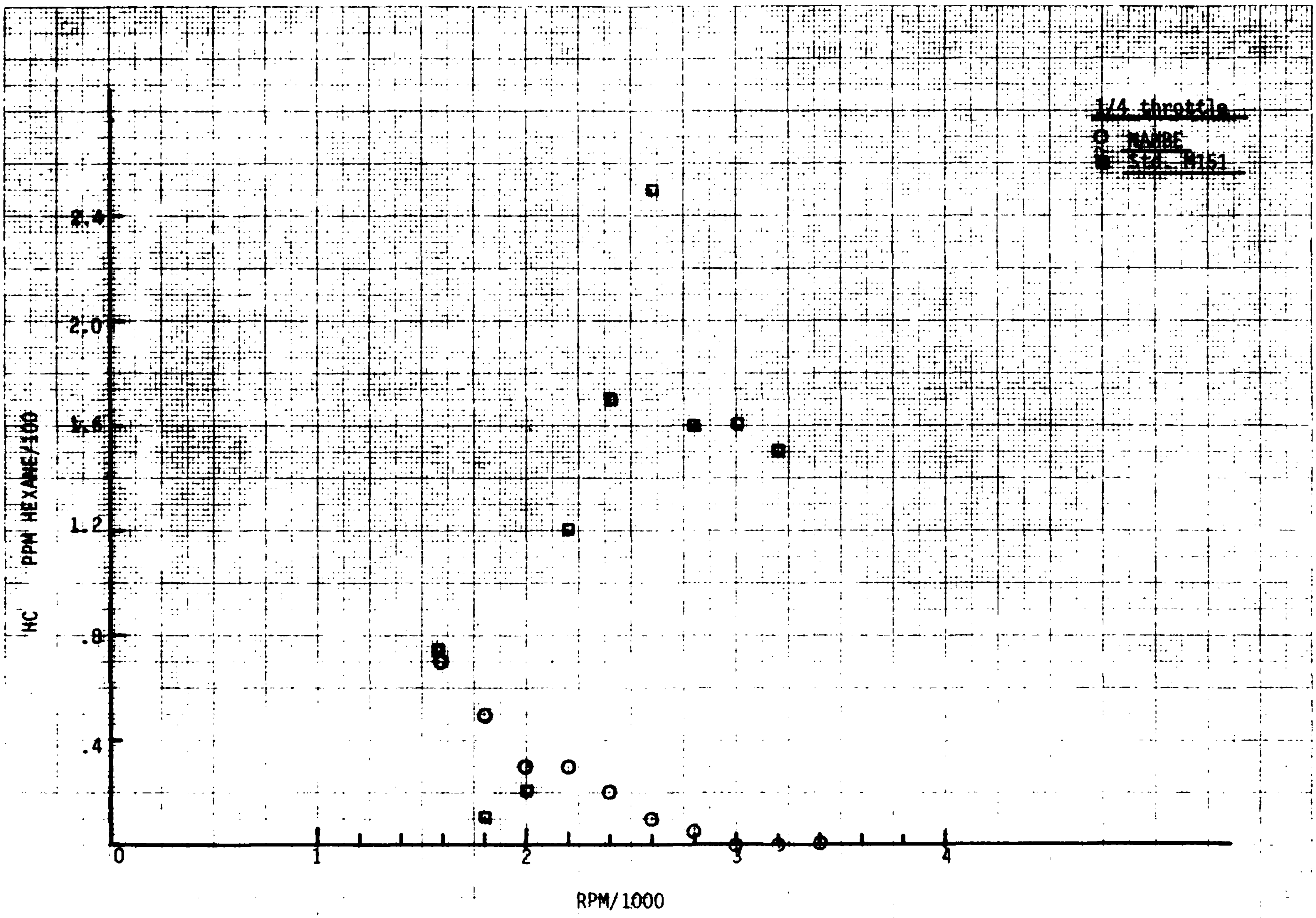
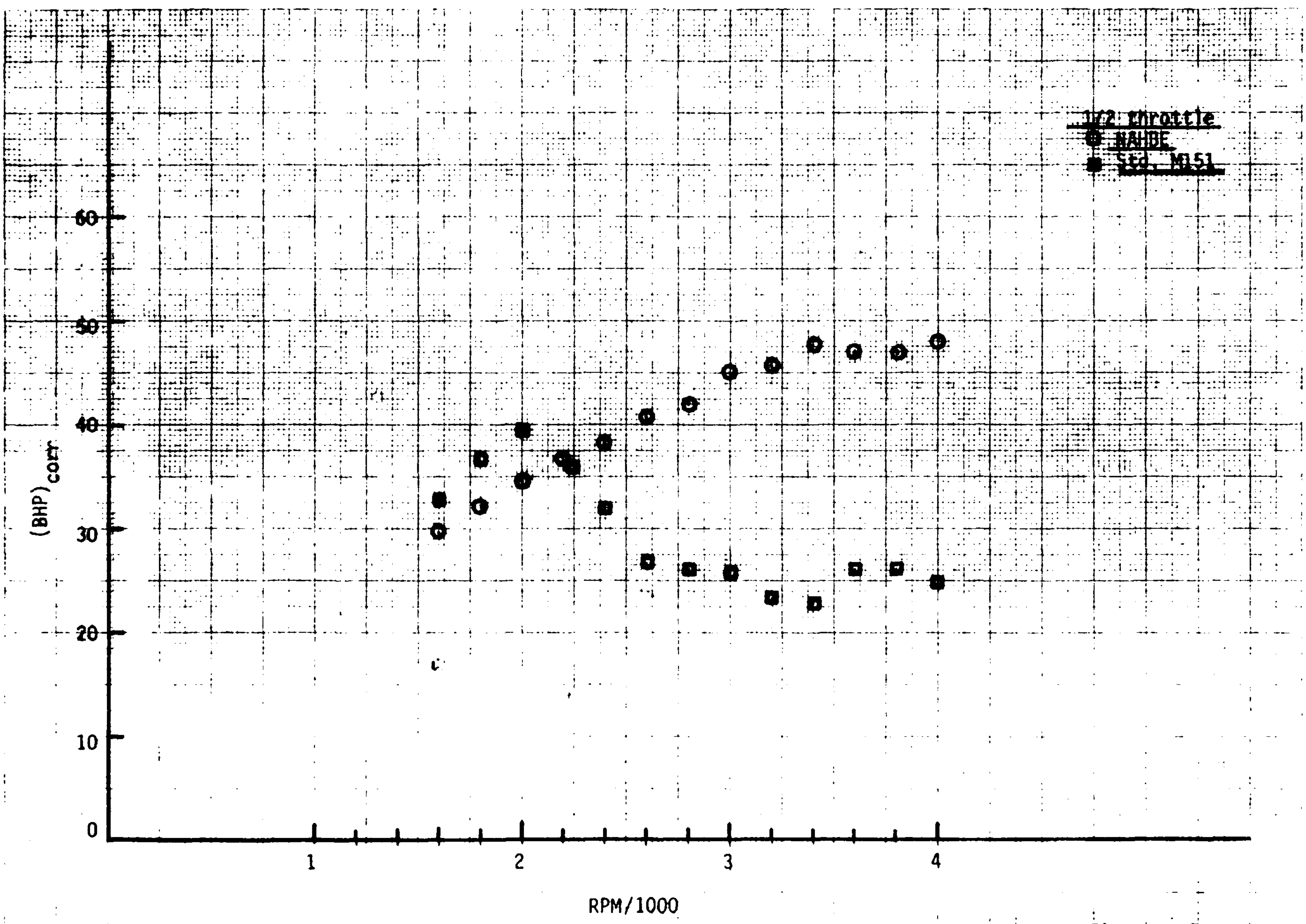

1/4 throttle
NAMBE
Std. M151
HC PPM HEXANE/100
2.4
2.0
1.6
1.2
.8
.4
0
1
2
3
4
RPM/1000

Figure V-4



1/2 throttle
NAHDE
Std. M151
60
50
40
30
20
10
0
1
2
3
4
RPM/1000
$(BHP)_{corr}$

Figure V-5

K-E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO. 46 1513

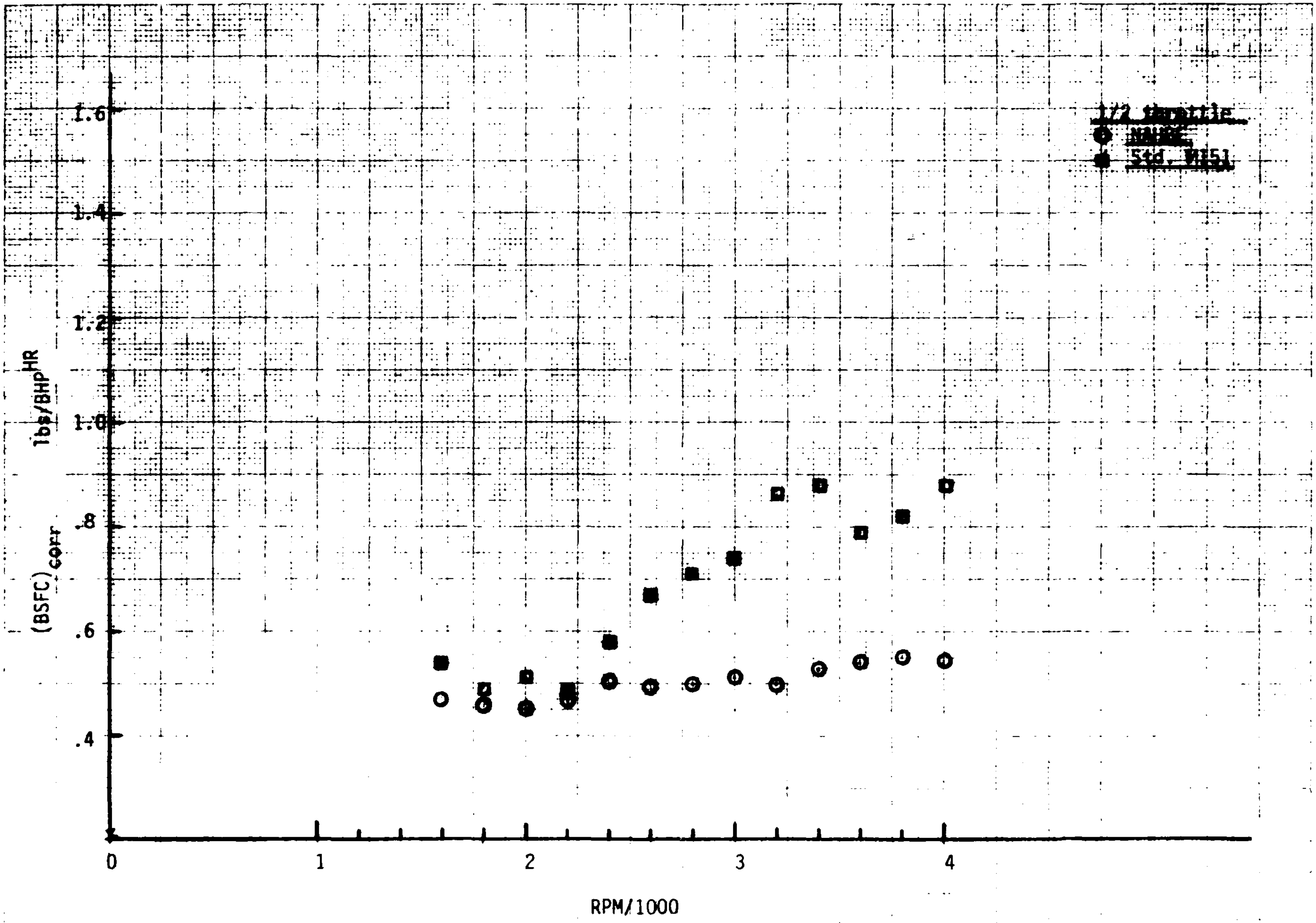


Figure V-6

K•E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. 46 1513

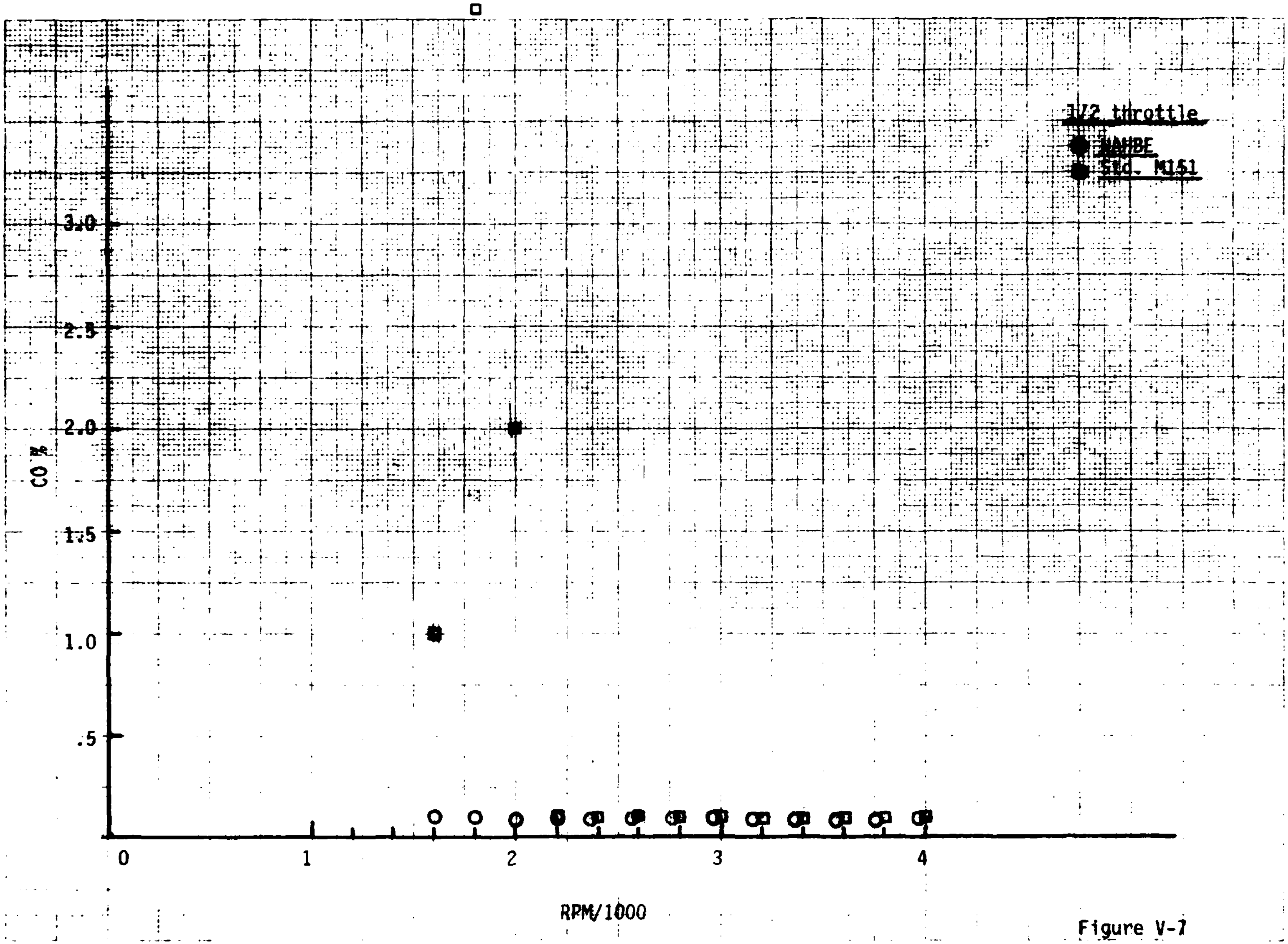


Figure V-7

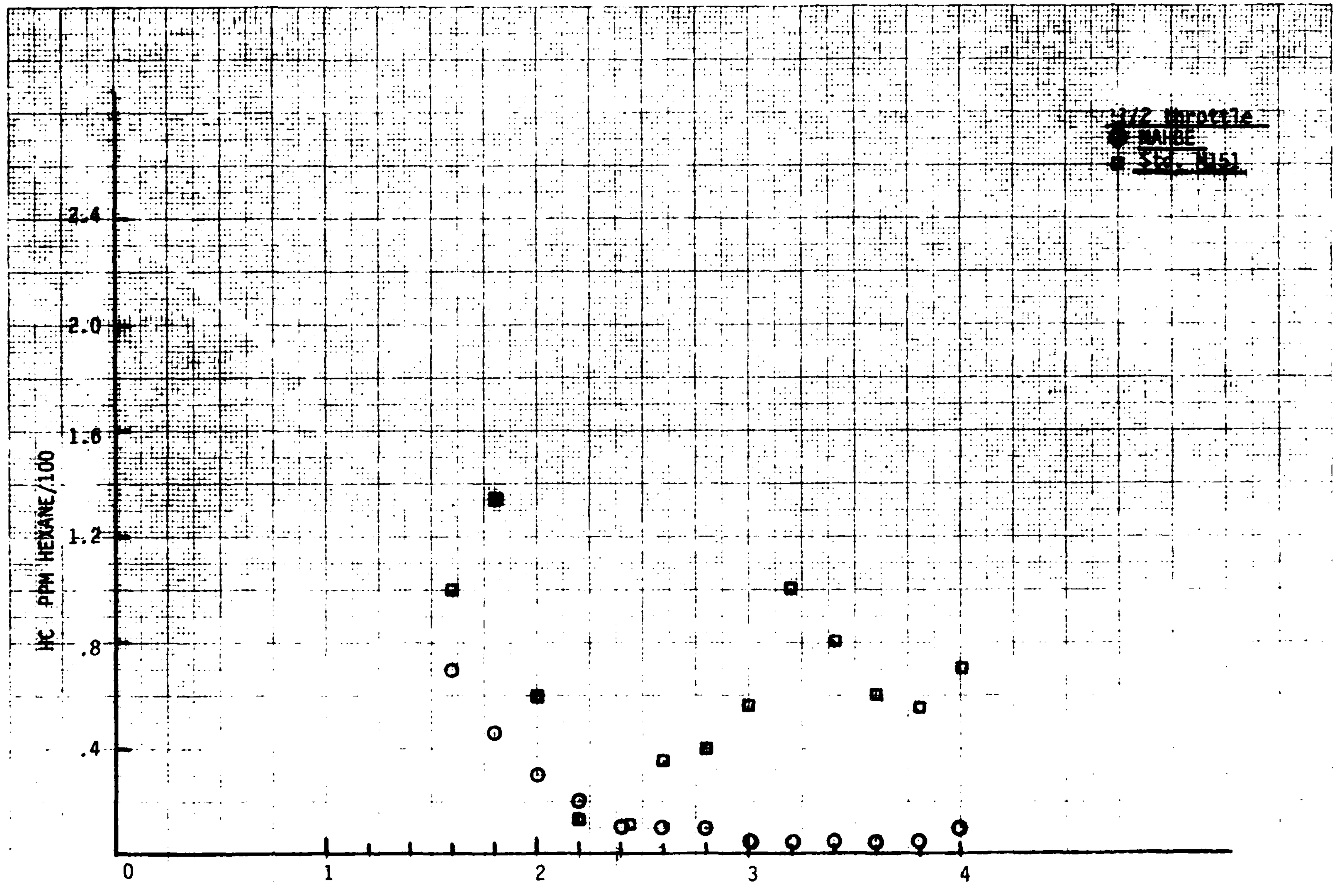


Figure V-8

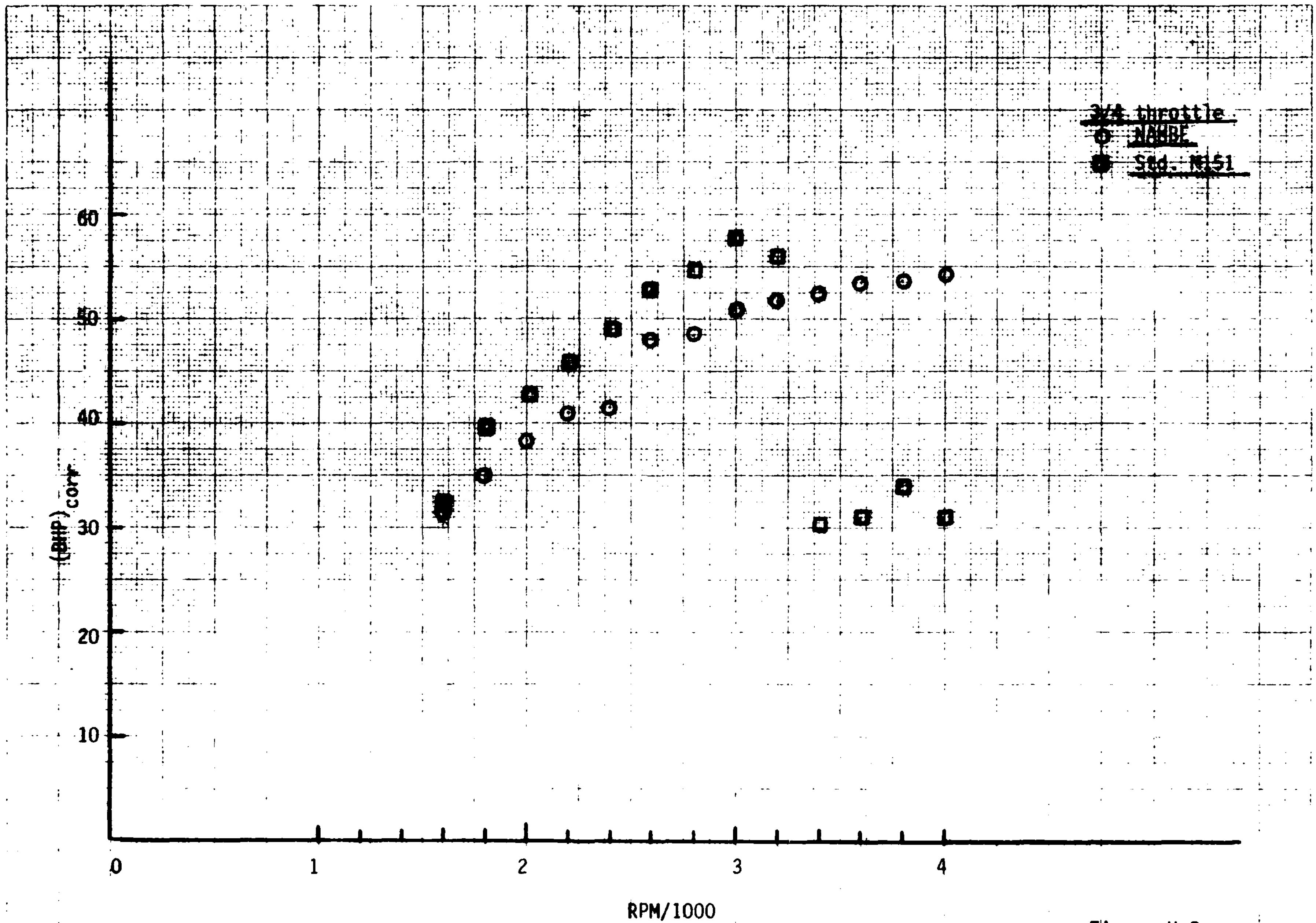

3/4 throttle
NABBE
Std. M151
60
50
40
30
20
10
(BHP)corr
0
1
2
3
4
RPM/1000

Figure V-9

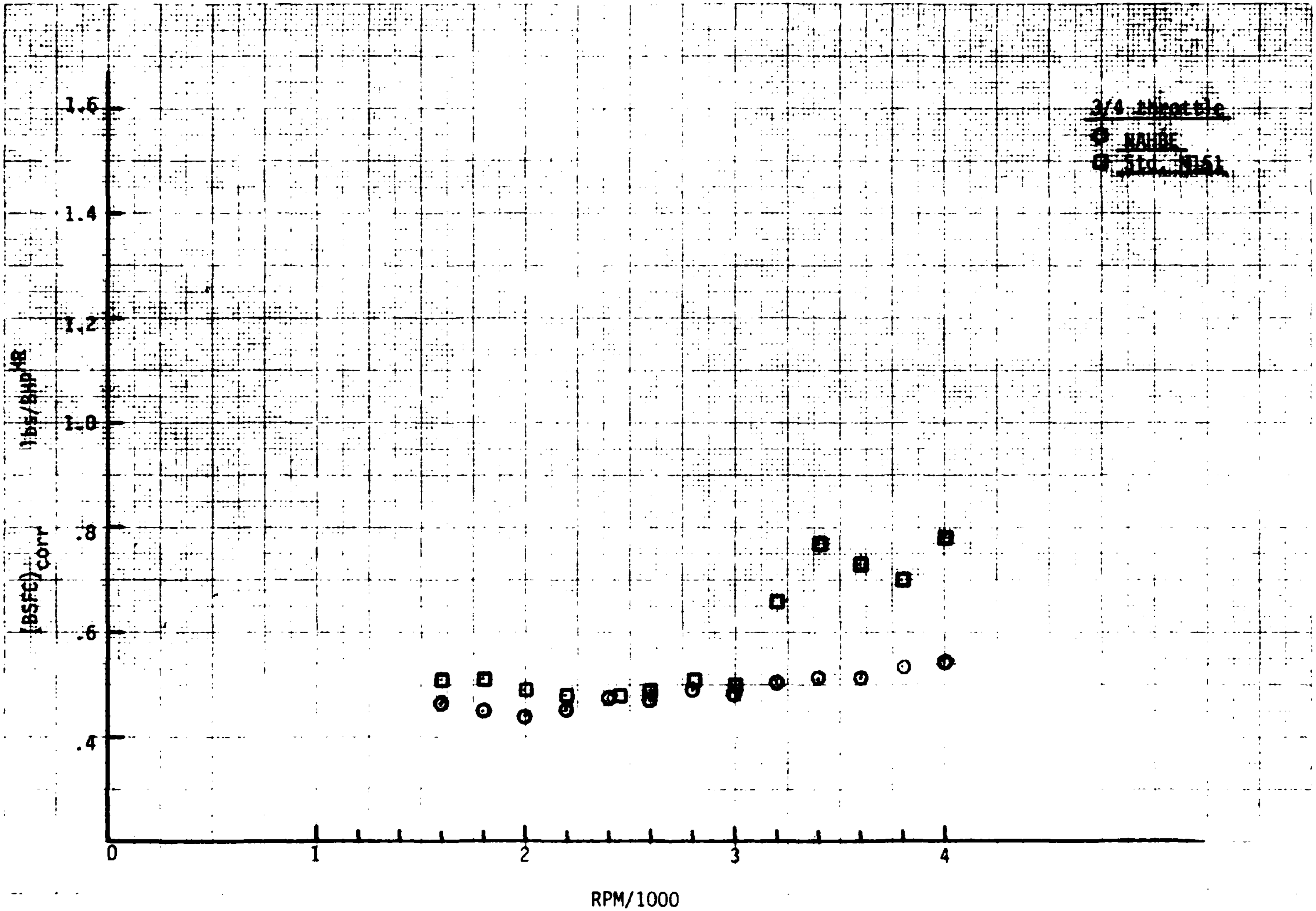

3/4 throttle
NAHBE
Std. M151
(BSFC) corr lbs/BHP HR
1.6
1.4
1.2
1.0
.8
.6
.4
0
1
2
3
4
RPM/1000

Figure V-10

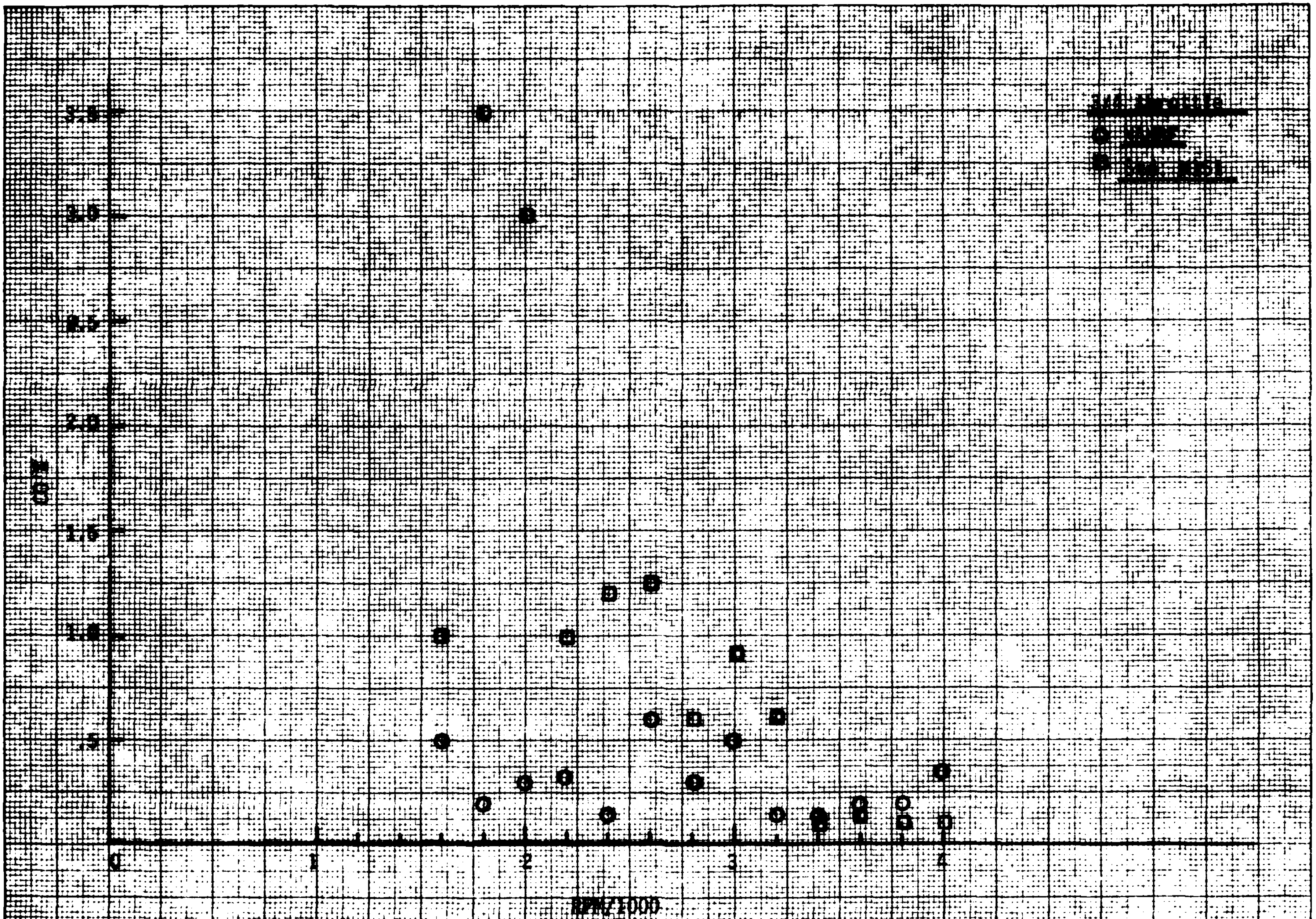
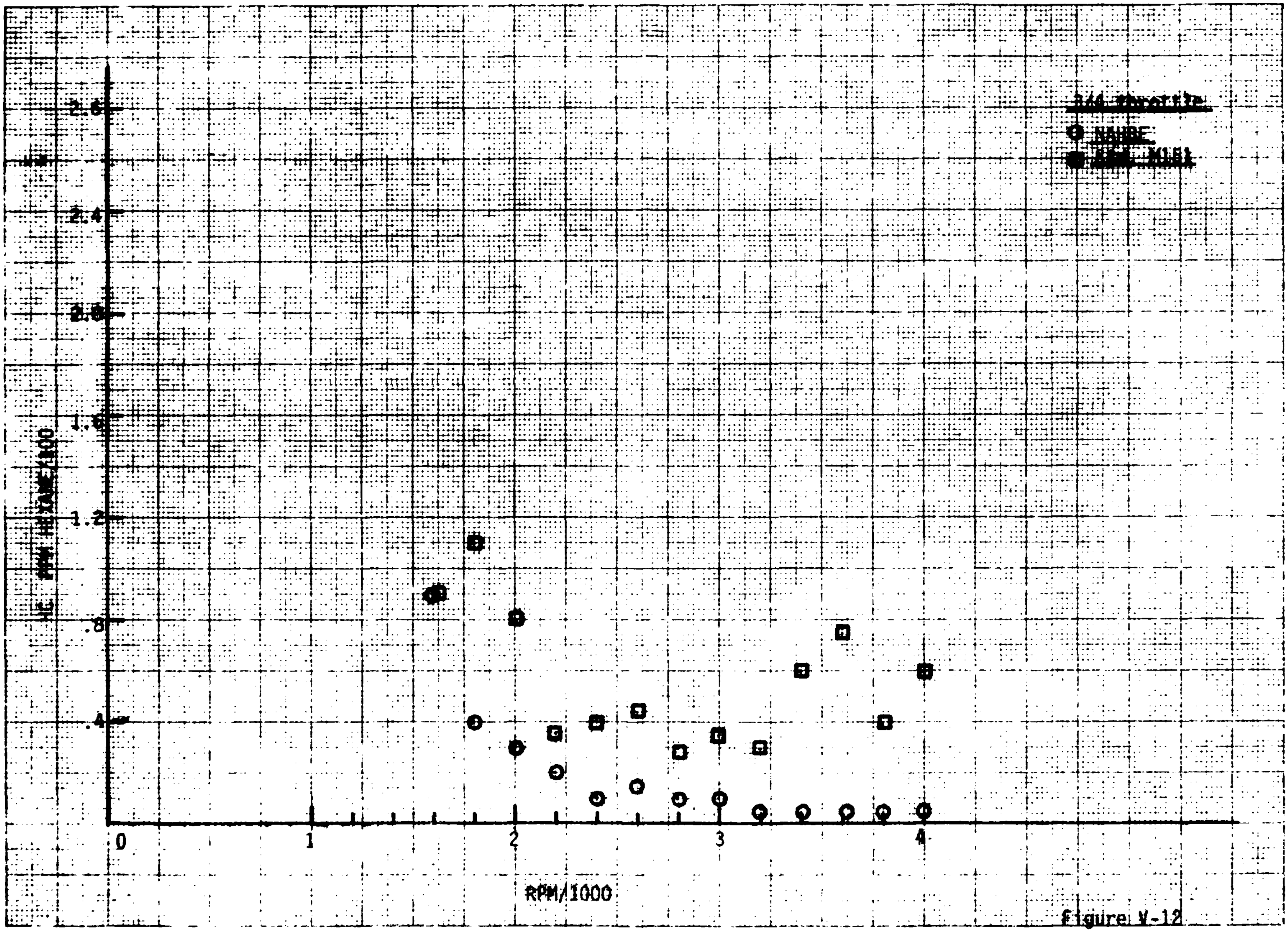
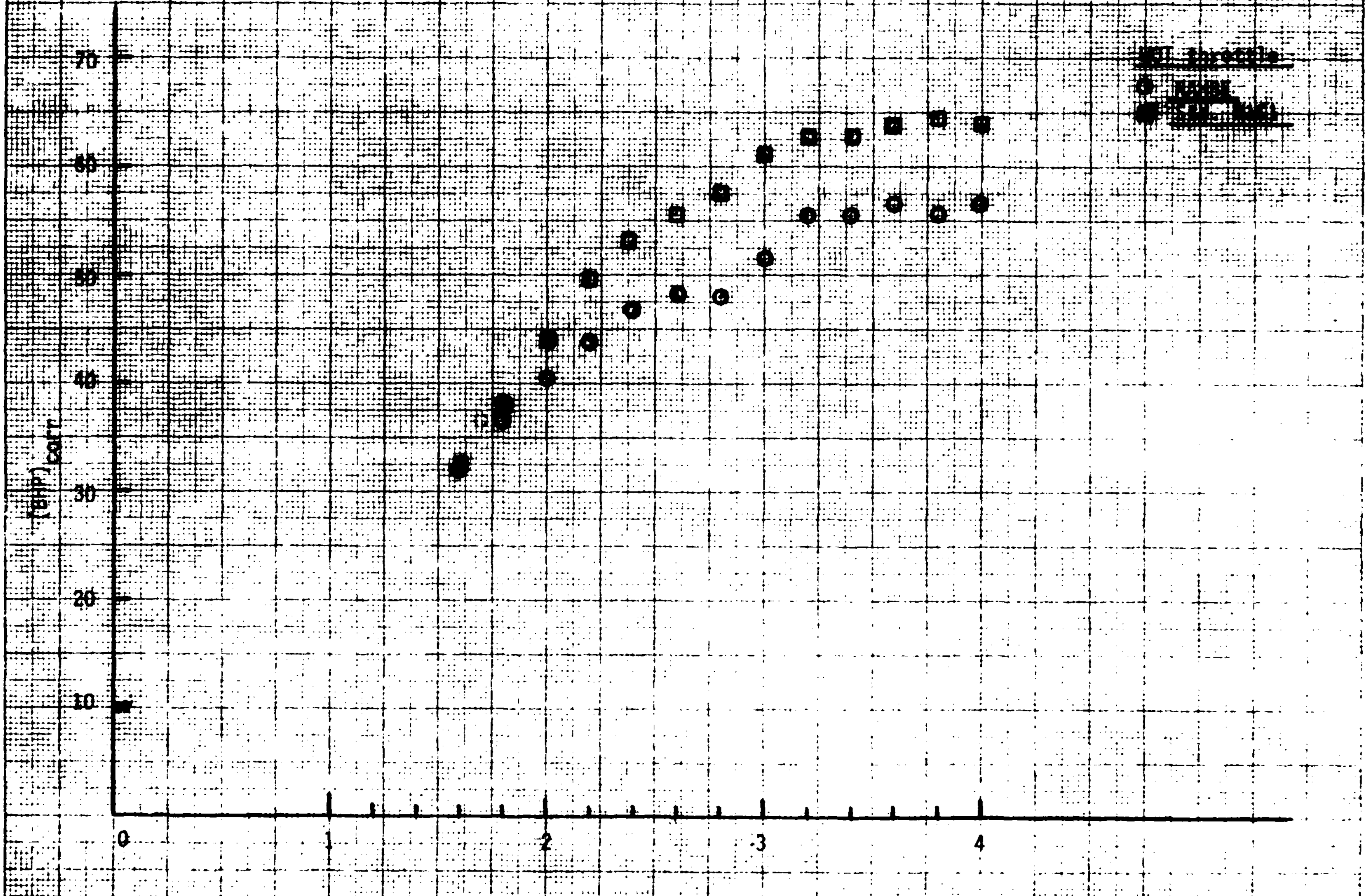


Figure V-11



3/4 Throttle
NAUBE
RPM/1000
HC PPM HEXANE/100
0
1
2
3
4
.4
.8
1.2
1.6
2.0
2.4
2.6

Figure V-12



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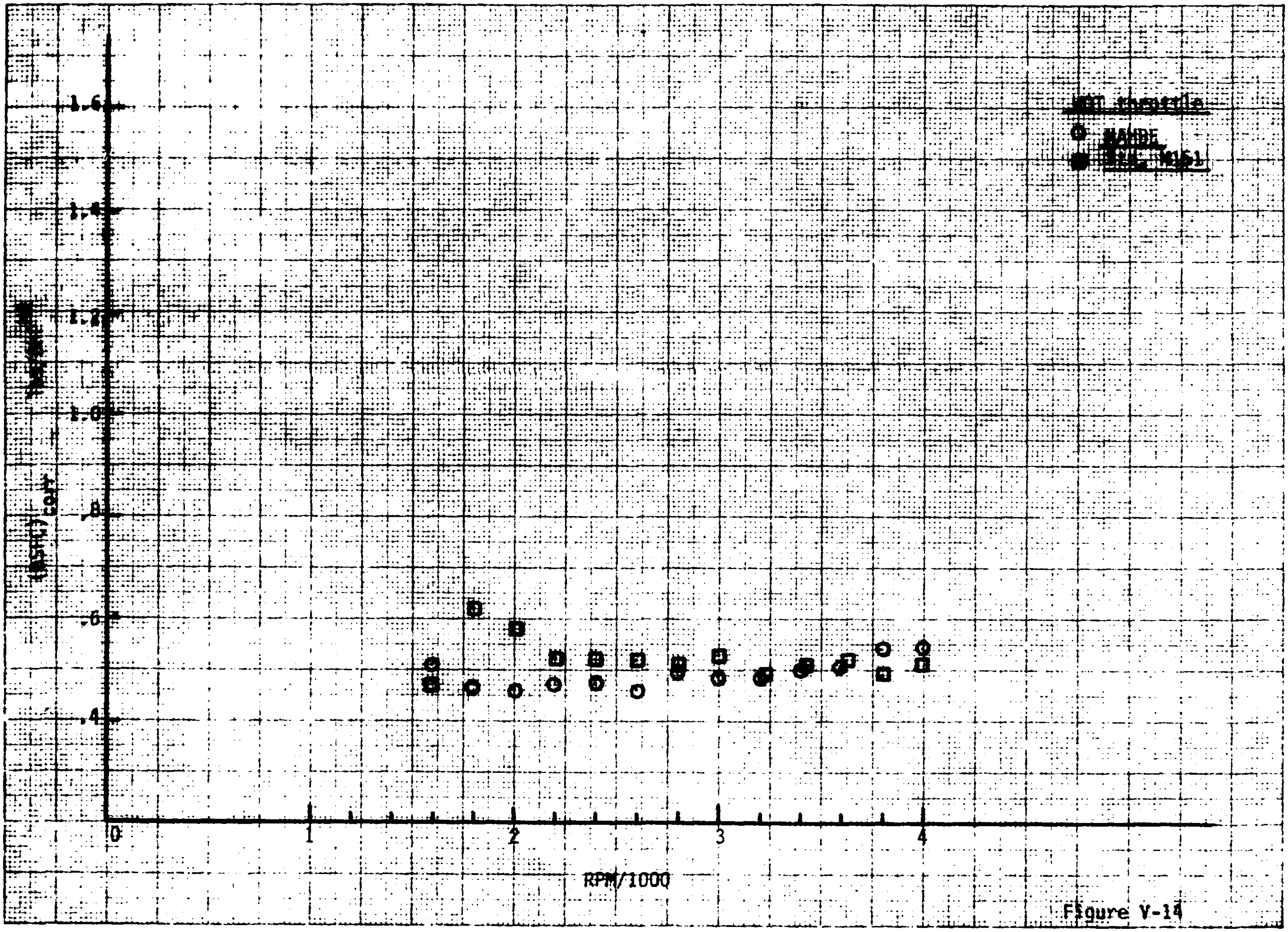

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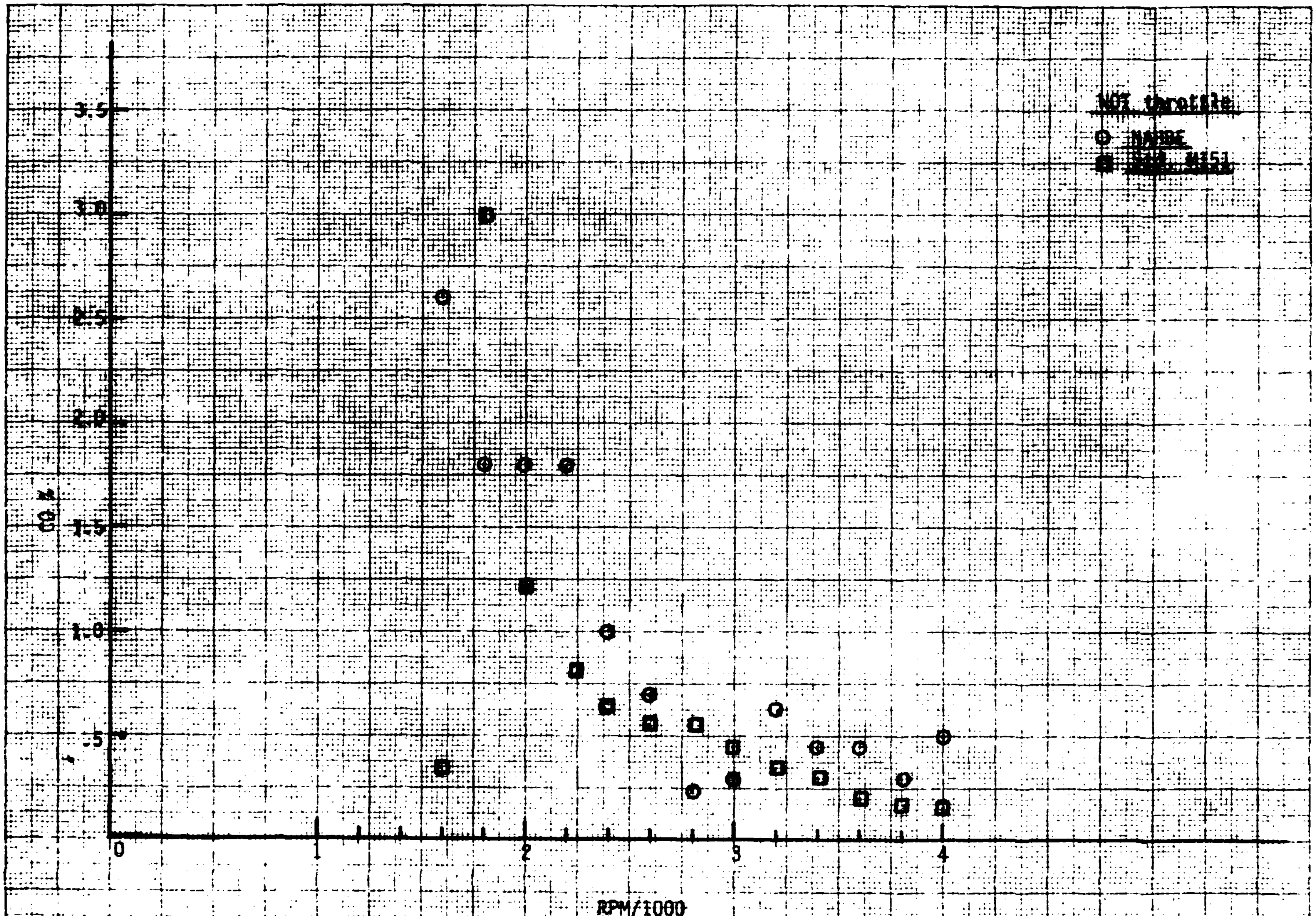


Figure V-15

10 X 10 TO THE CENTIMETER 46 1512
KEUFFEL & ESSER CO.

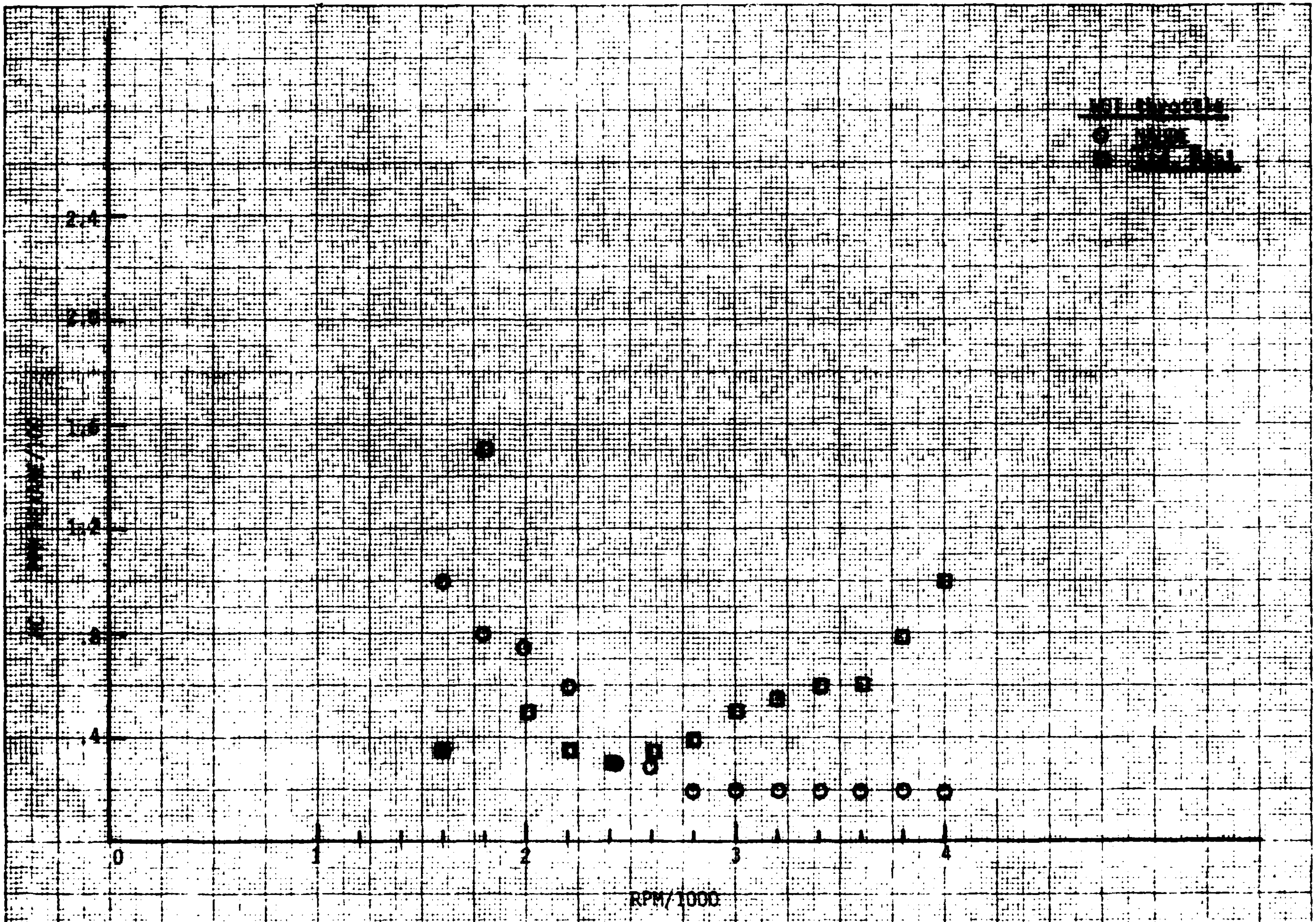


Figure V-16

46 1513

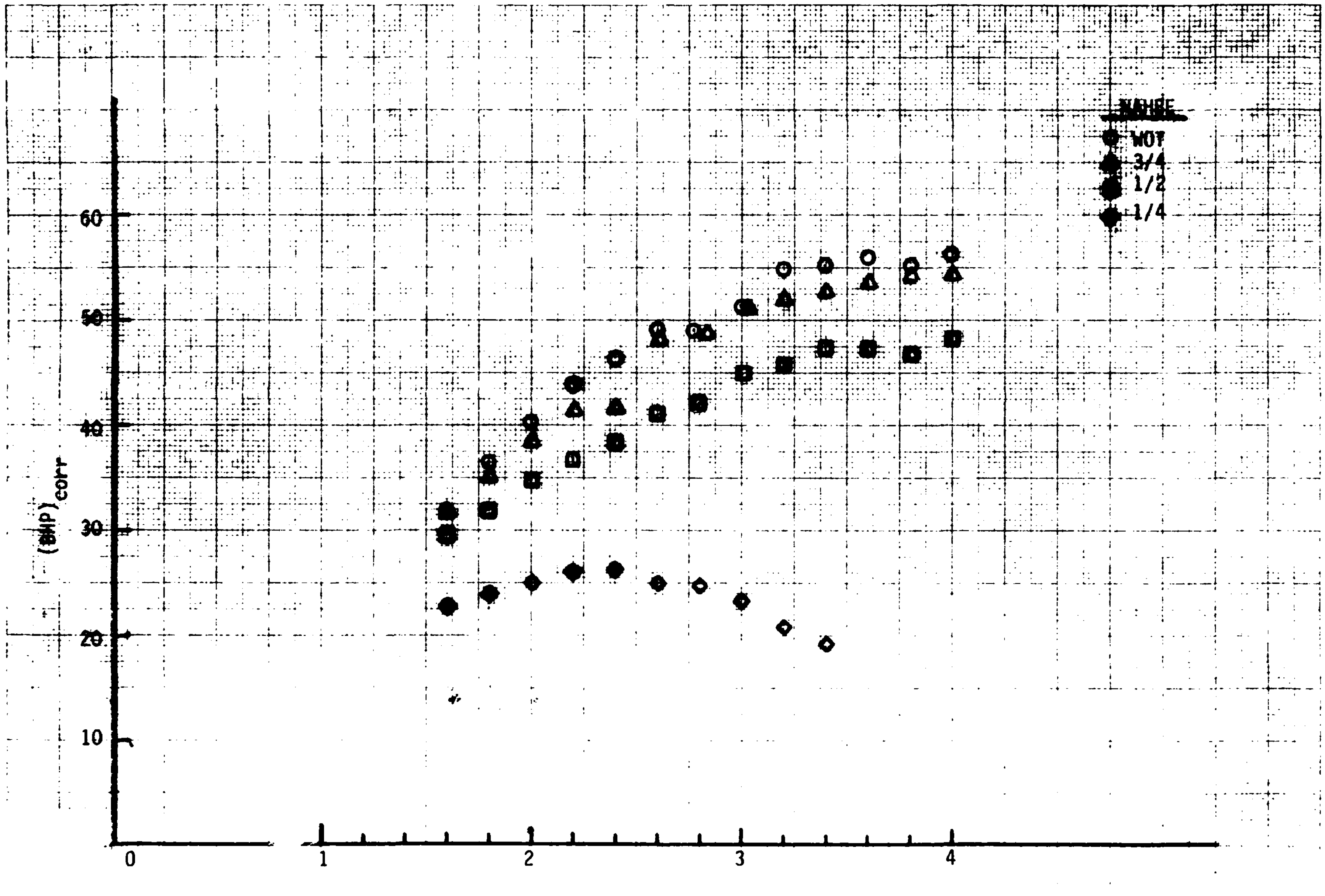


Figure V-17

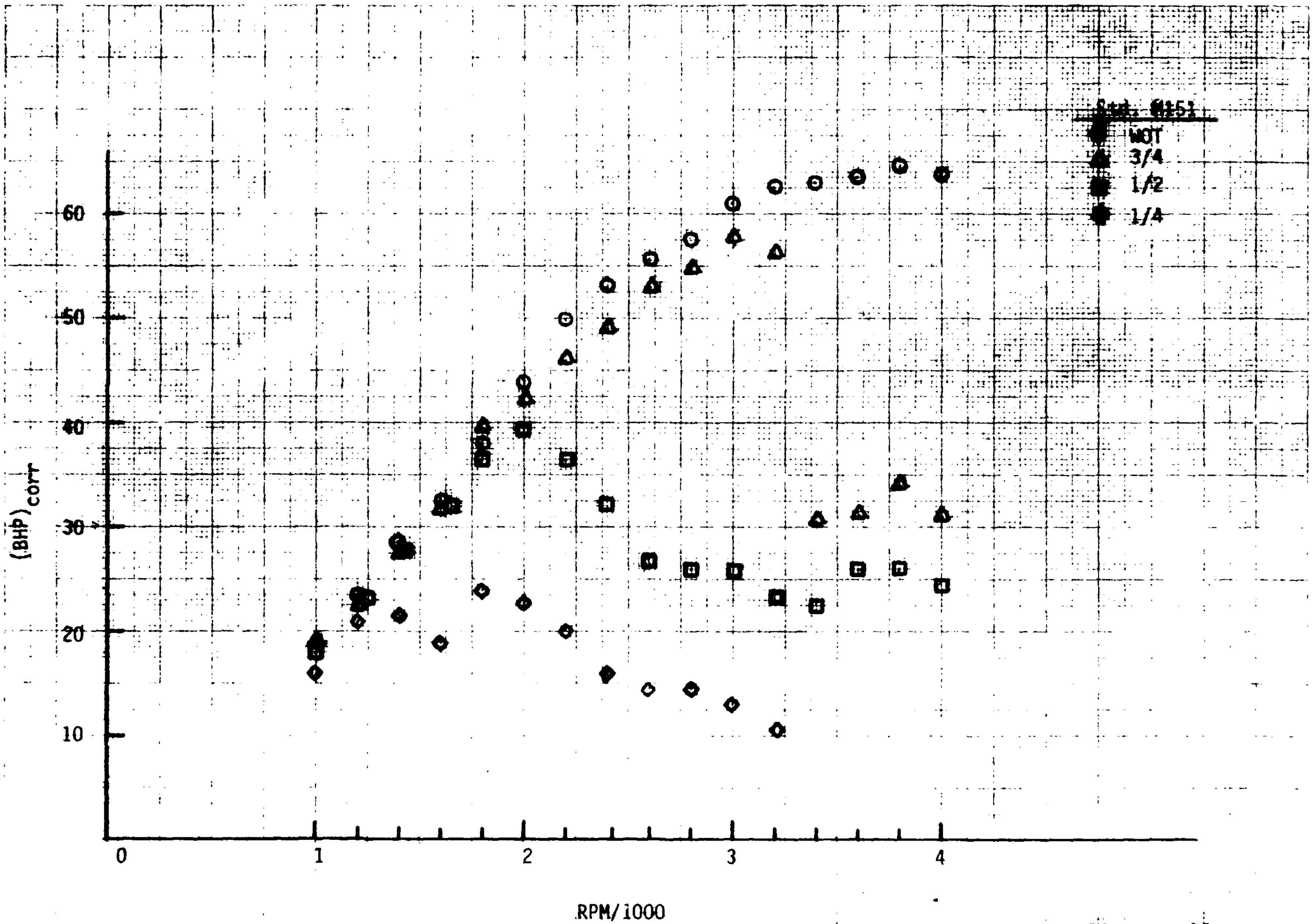


Figure V-18

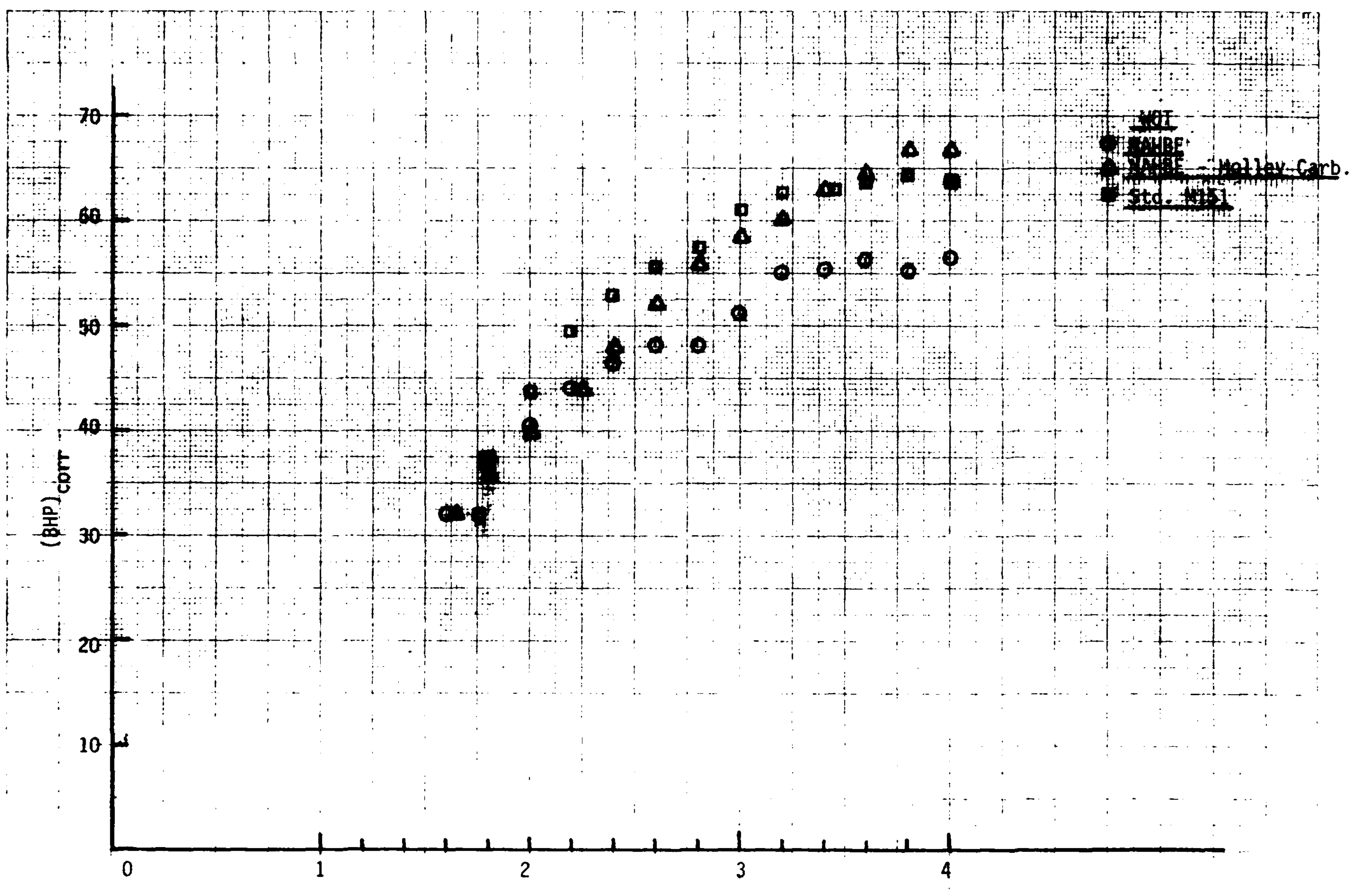
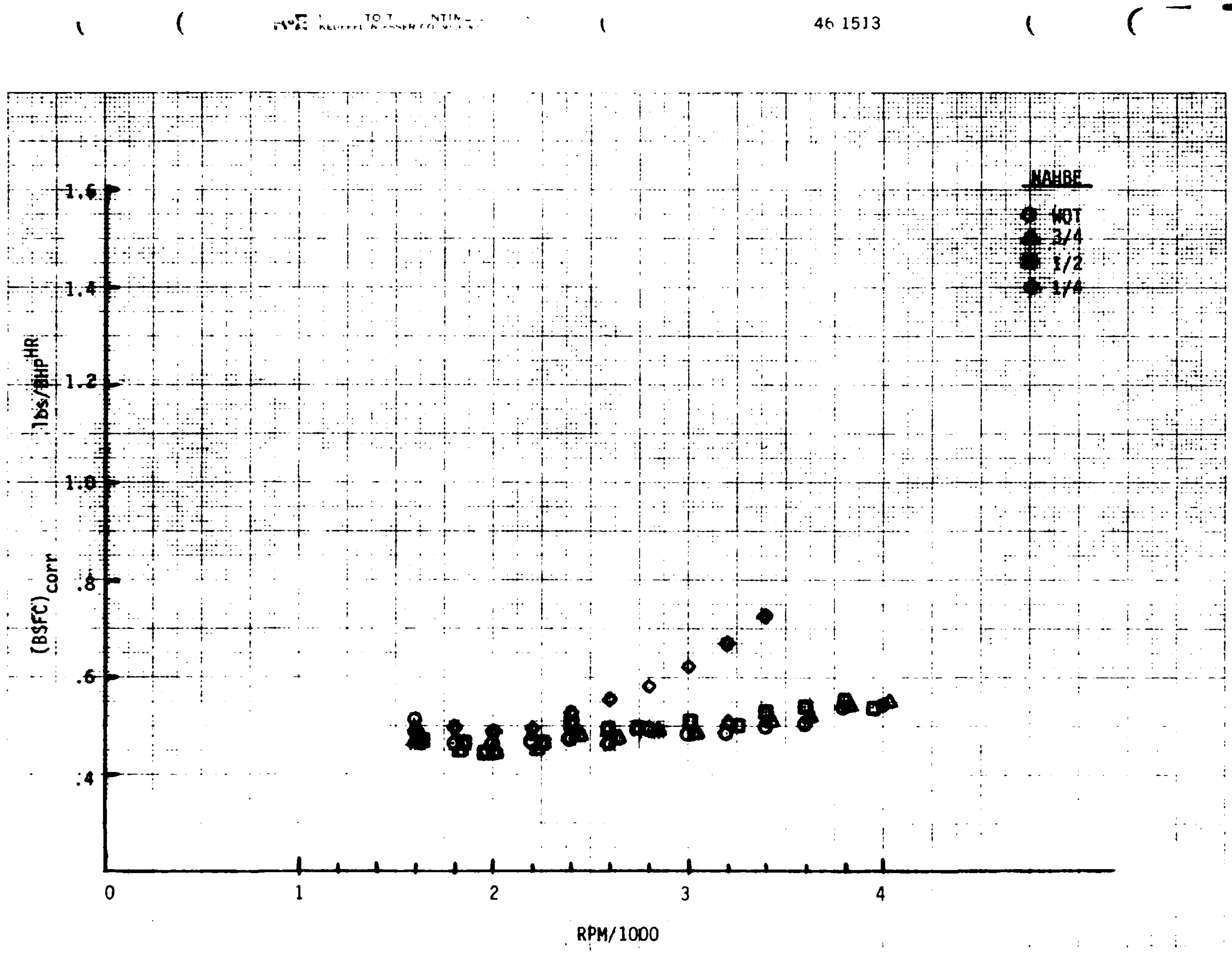

Holley Carb.
Std. M151
70
60
50
40
30
20
10
(BHP)corr
0
1
2
3
4
RPM/1000

Figure V-19



46 1513
NAHBE
WOT
3/4
1/2
1/4
1.6
1.4
1.2
1.0
.8
.6
.4
(BSFC)corr lbs/BHP HR
0
1
2
3
4
RPM/1000

Figure V-20

46 1513

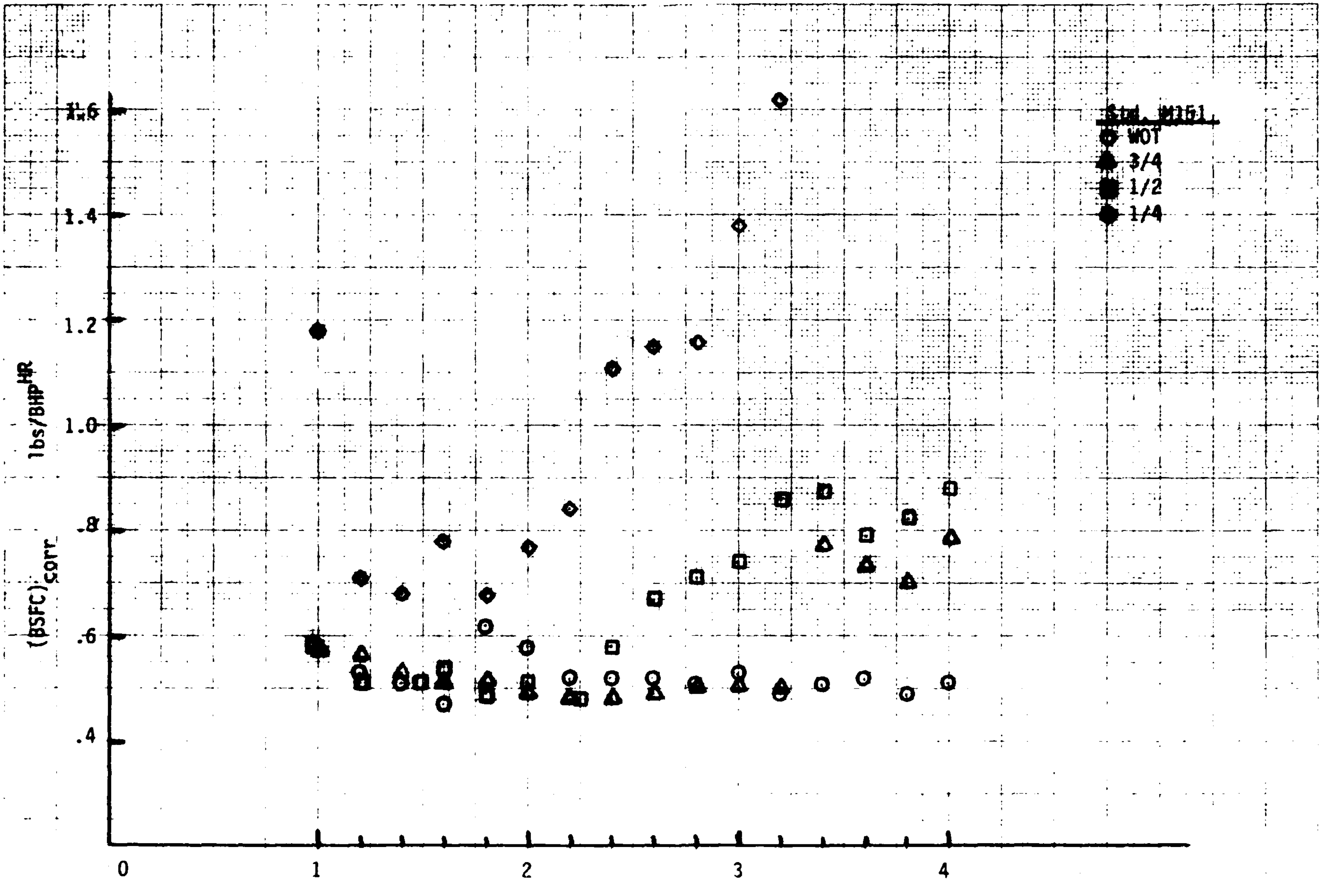


Figure V-21

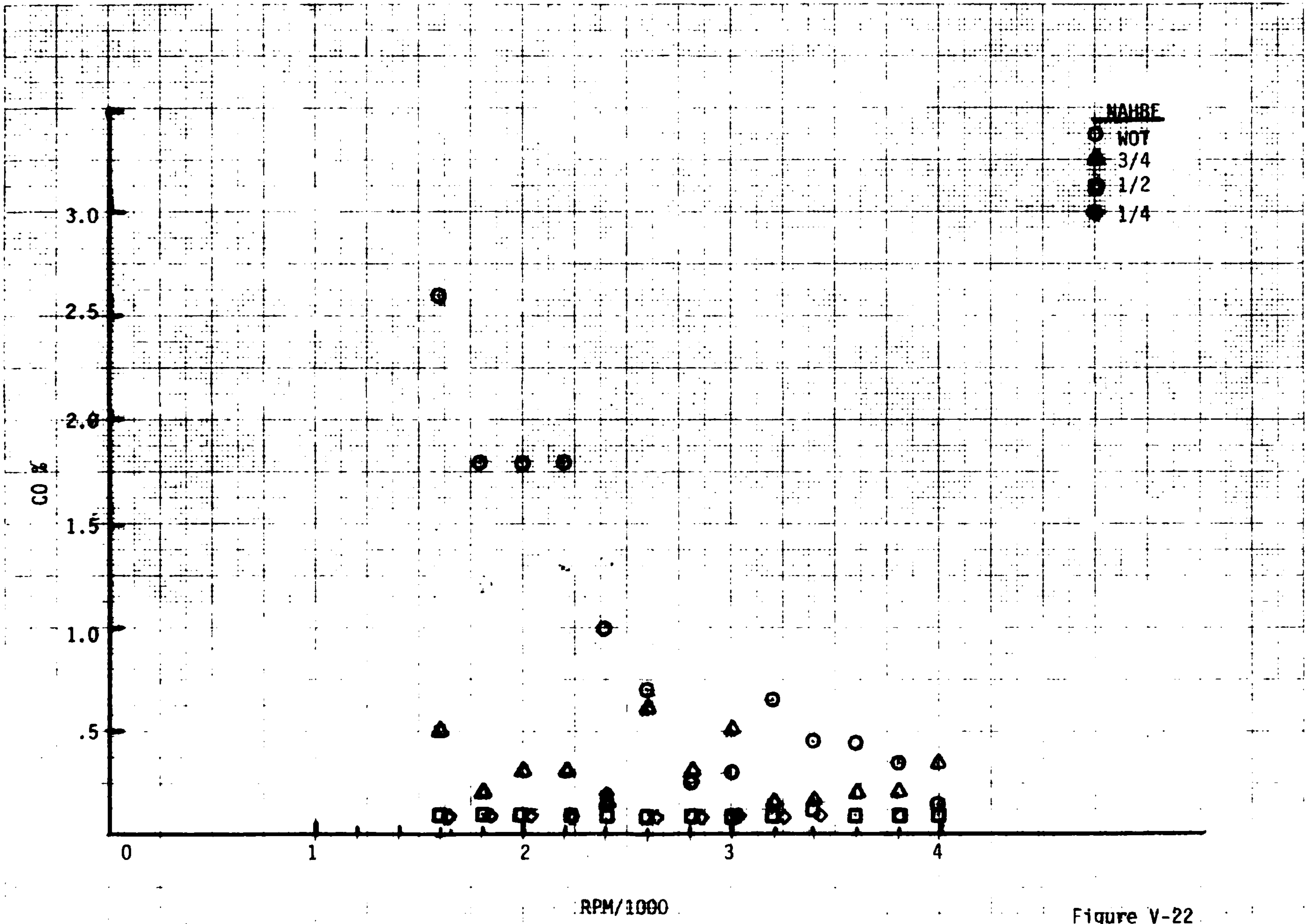


Figure V-22

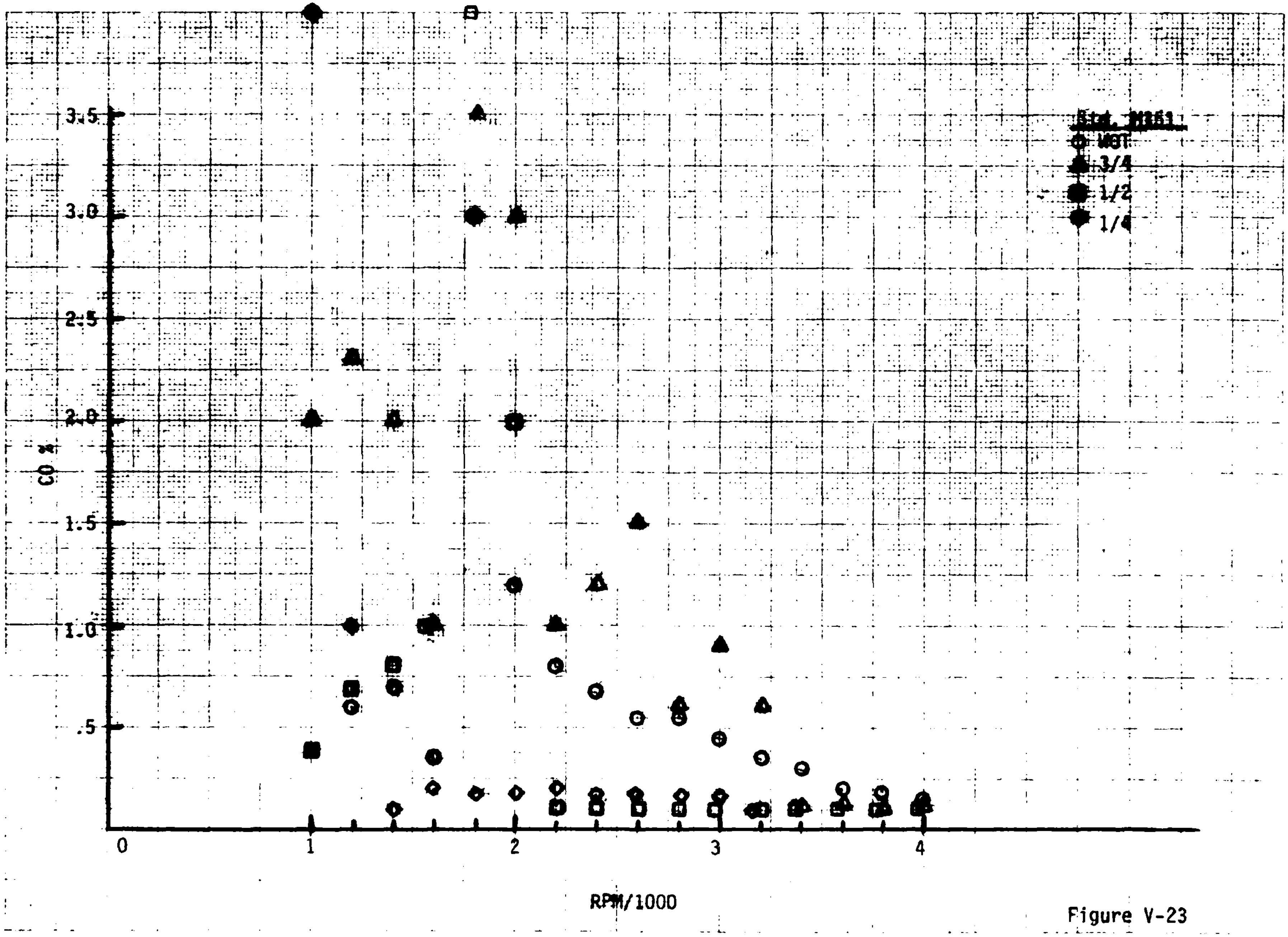


Figure V-23

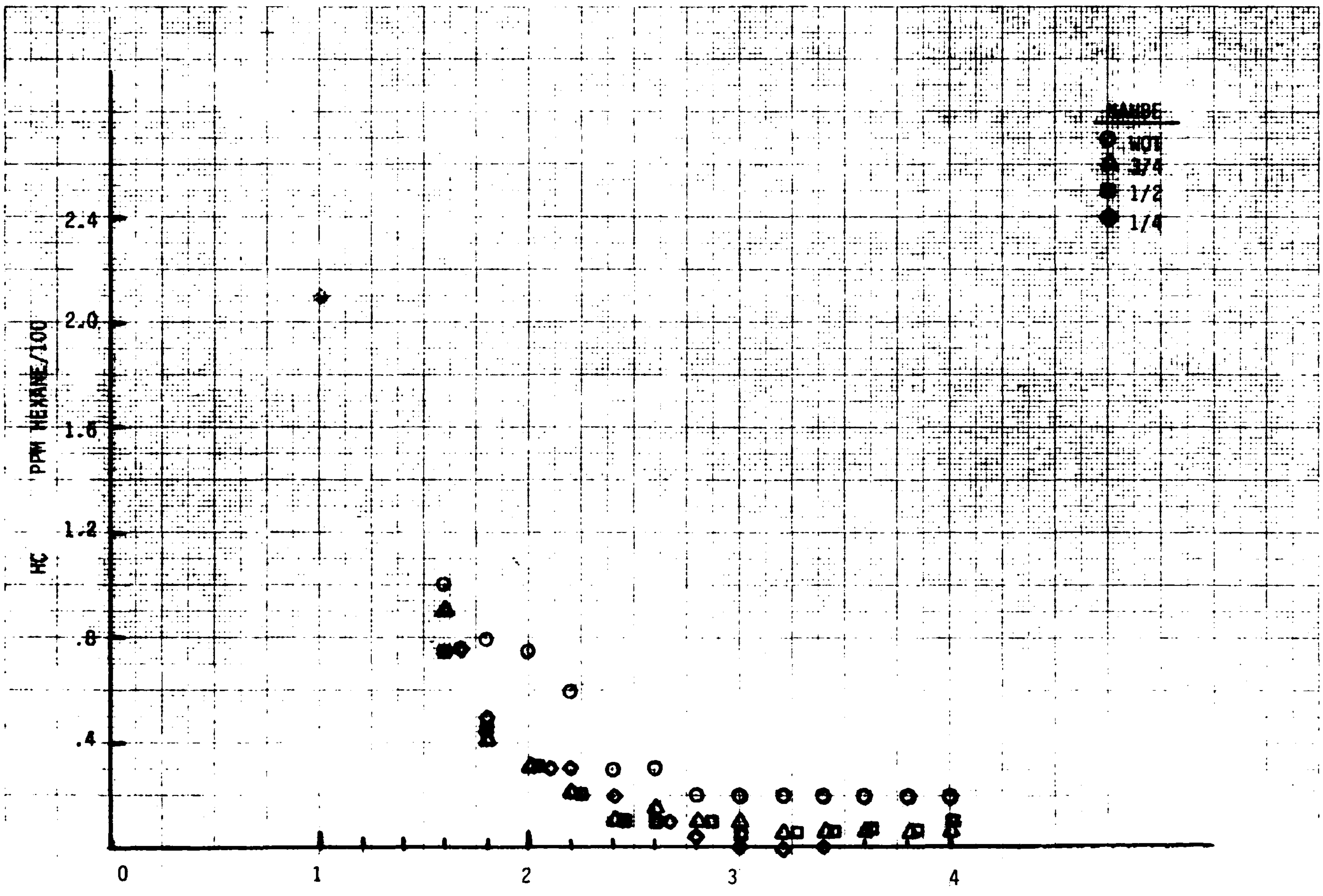

RANGE
WOT
3/4
1/2
1/4
HC PPM HEXANE/100
2.4
2.0
1.6
1.2
.8
.4
0
1
2
3
4
RPM/1000

Figure V-24

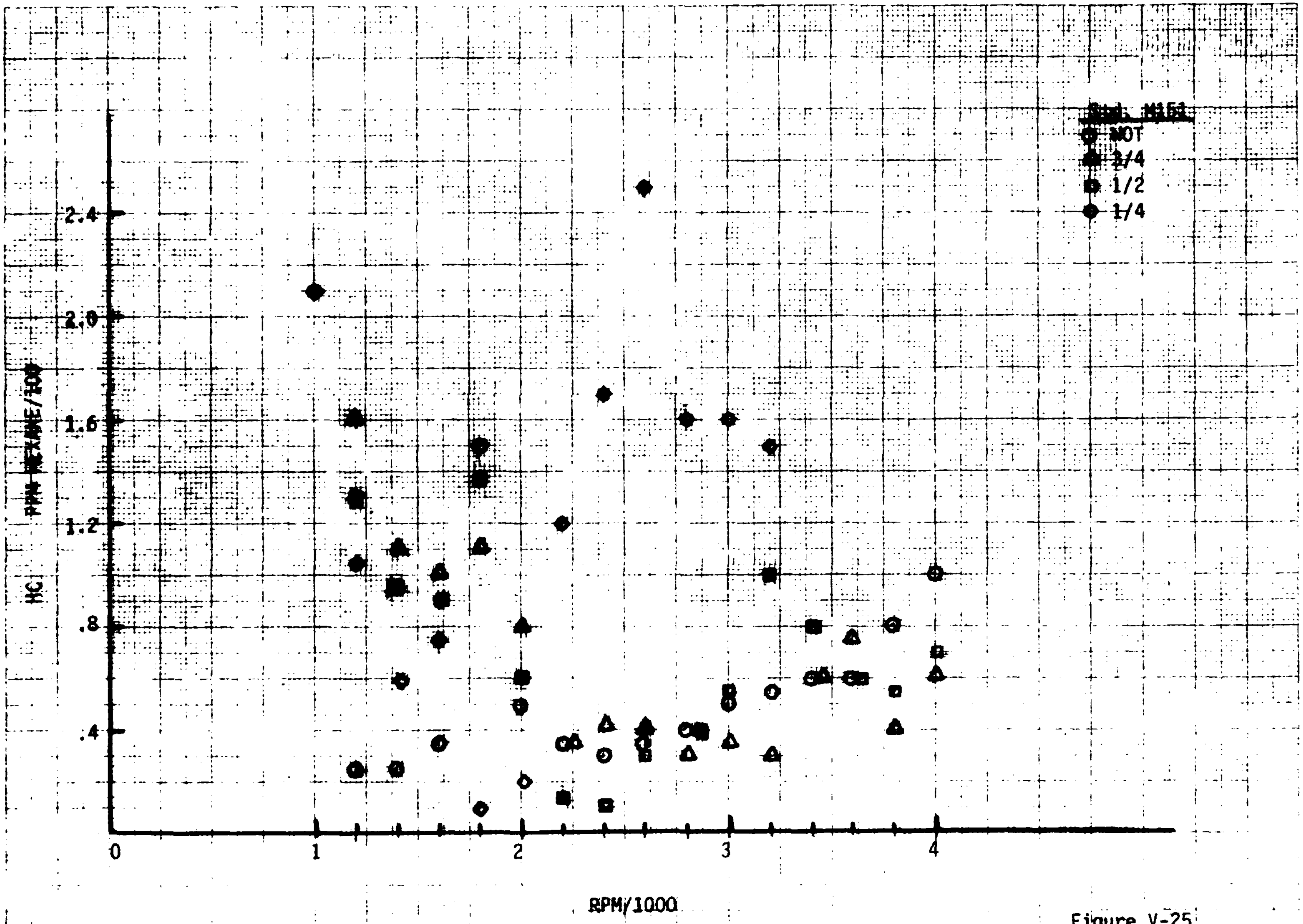

Std. M151
NOT
3/4
1/2
1/4
2.4
2.0
1.6
1.2
.8
.4
0
1
2
3
4
HC PPM HEXANE/100
RPM/1000

Figure V-25

K·E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO. 46 1513

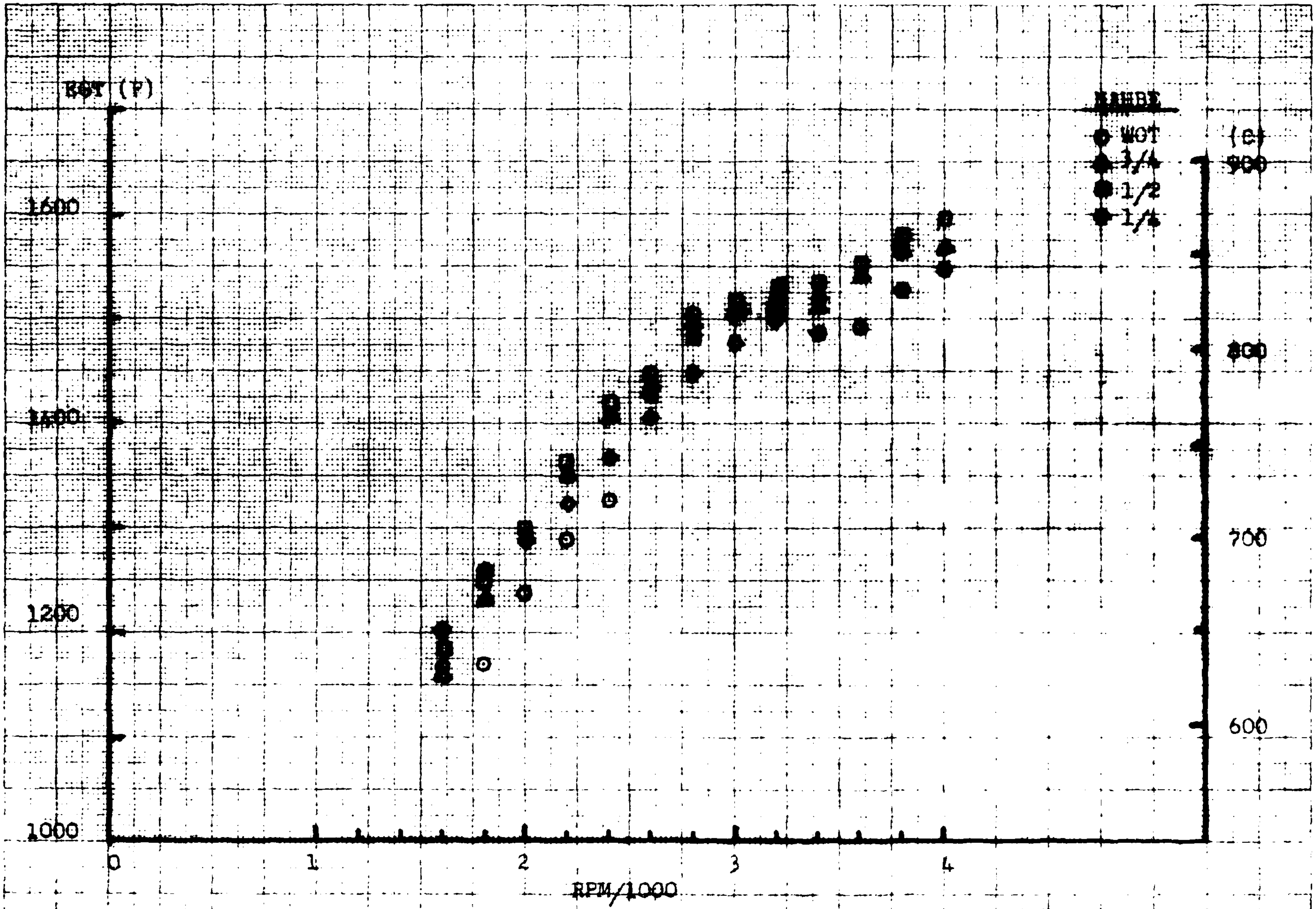


Figure V-26

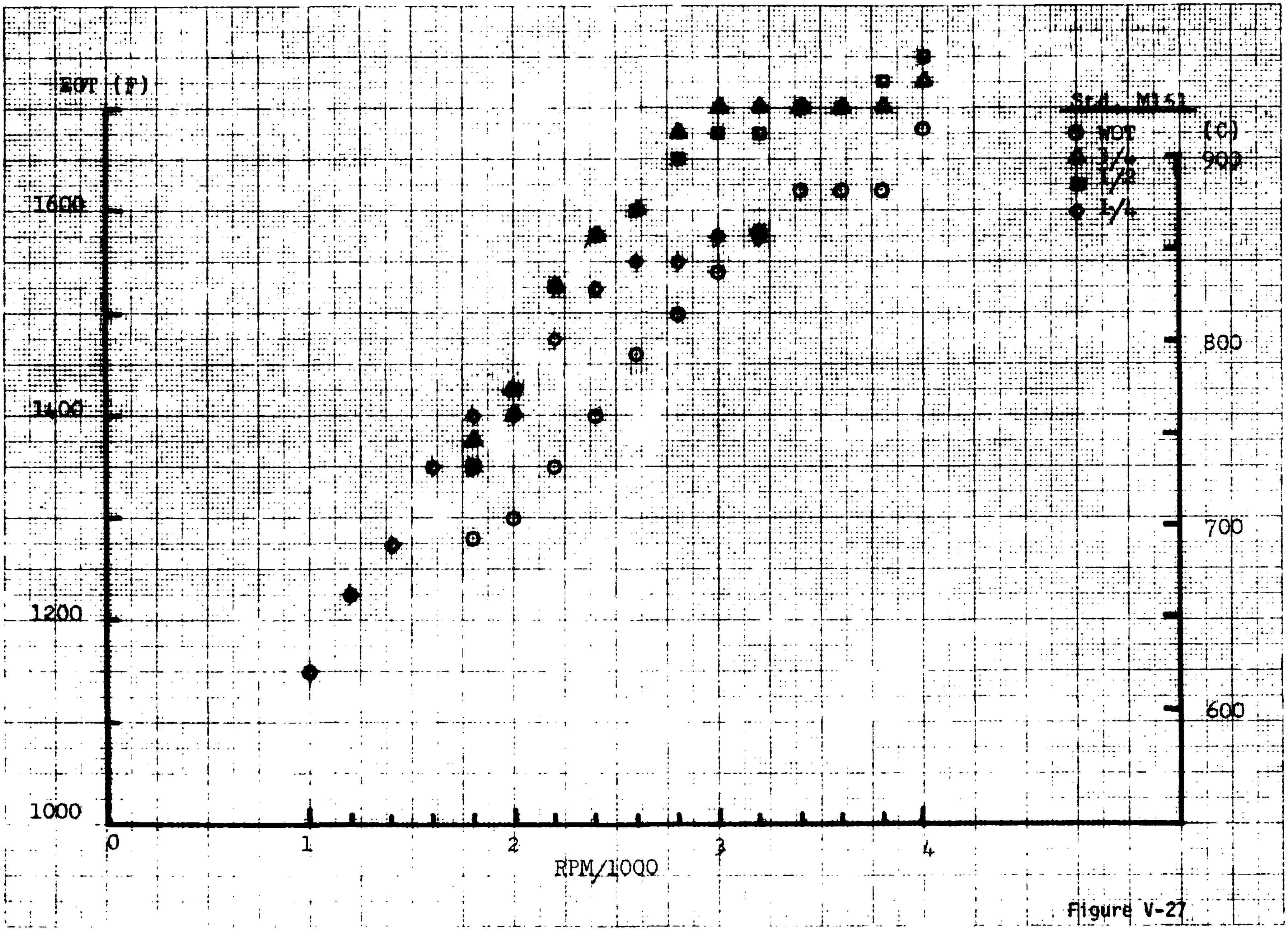

EOT (F)
1600
1400
1200
1000
Std. M151
WOT
3/4
1/2
1/4
(C)
900
800
700
600
0
1
2
3
4
RPM/1000

Figure V-27

46 1513

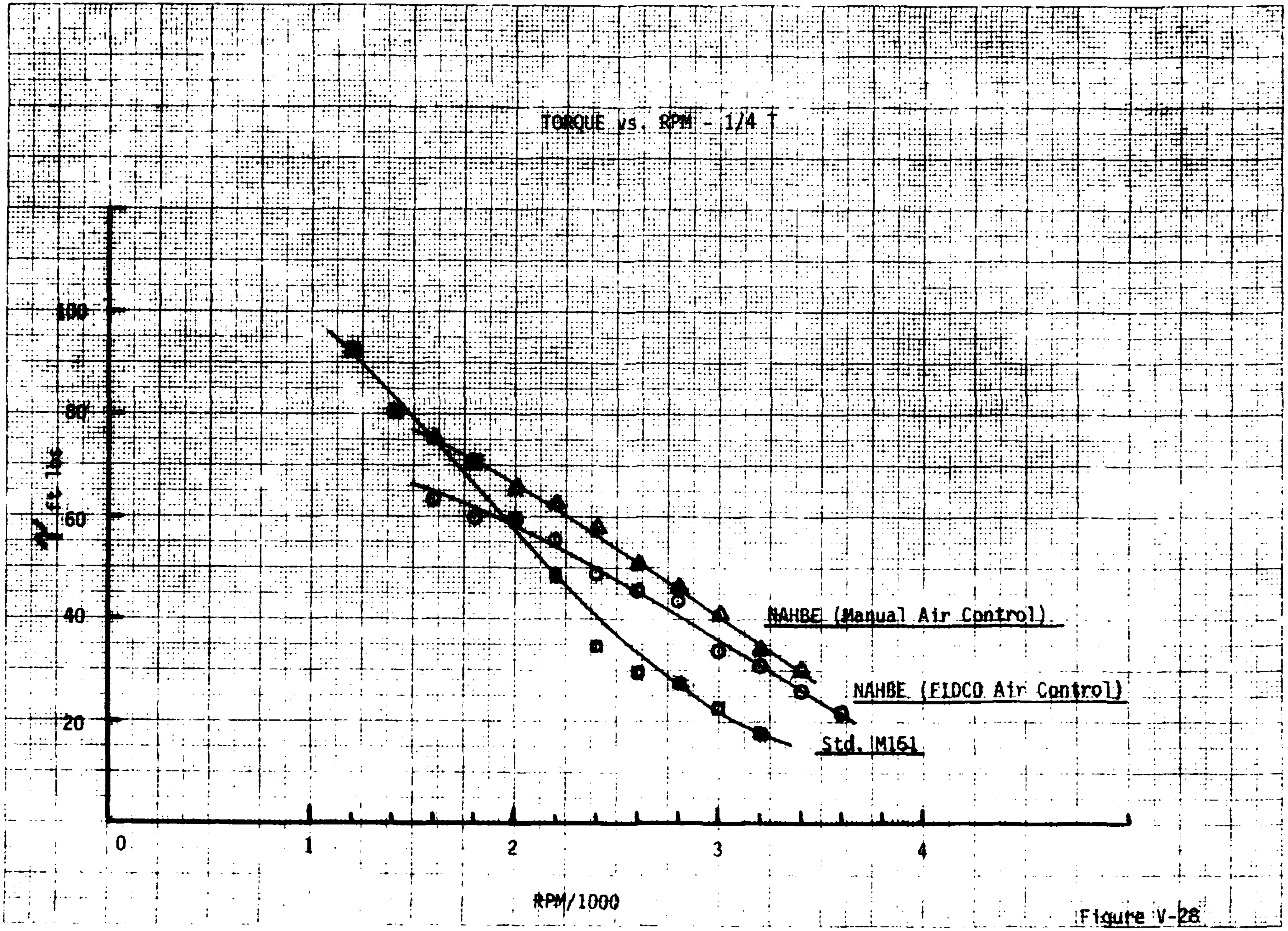
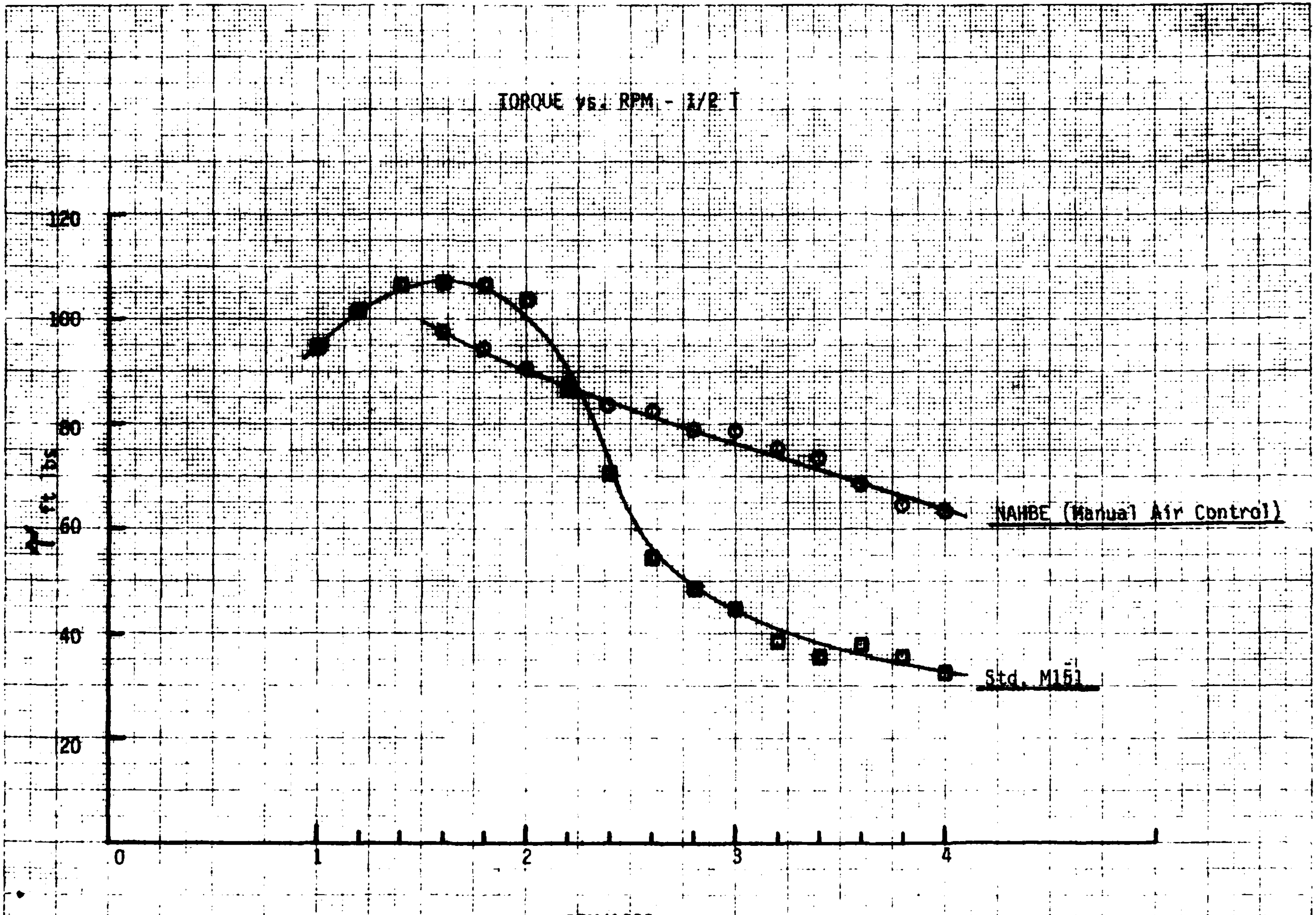


Figure V-28



TORQUE vs. RPM - 1/2 T
T ft lbs
120
100
80
60
40
20
0
1
2
3
4
RPM/1000
NAHBE (Manual Air Control)
Std. M151

Figure V-29

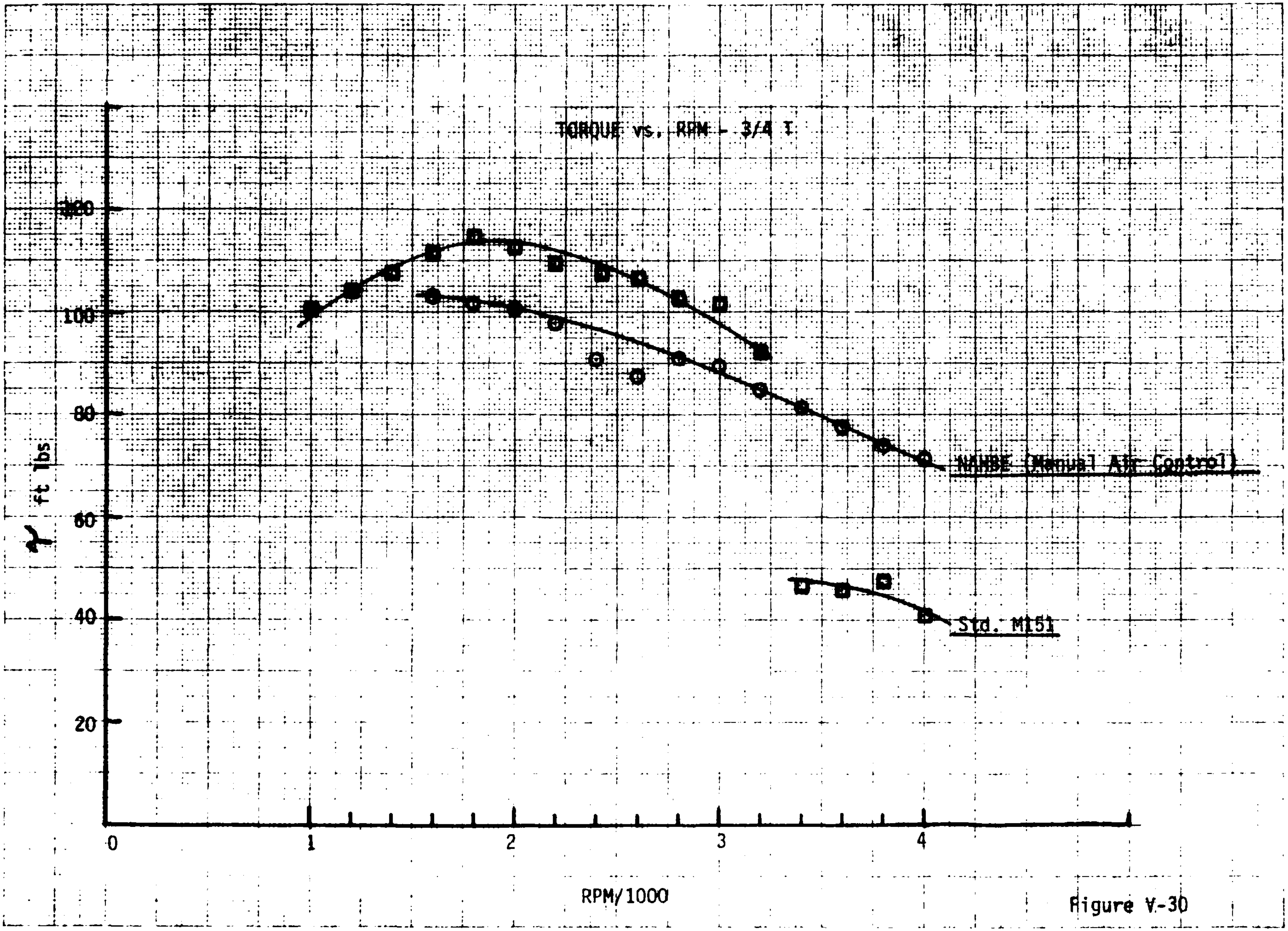

TORQUE vs. RPM - 3/4 T
ft lbs
120
100
80
60
40
20
0
1
2
3
4
RPM/1000
NAHBE (Manual Air Control)
Std. M151

Figure V-30

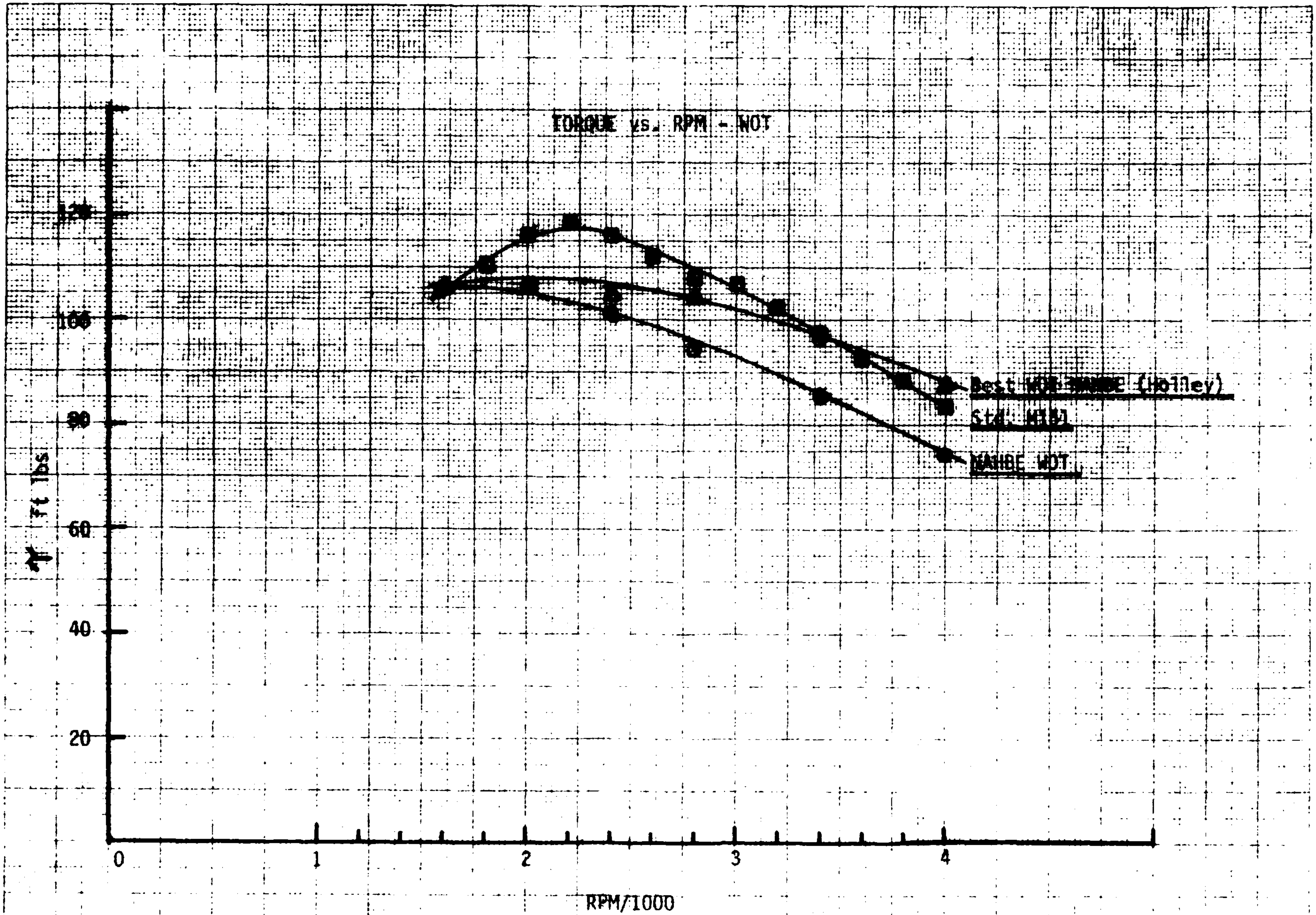

TORQUE vs. RPM - WOT
120
100
80
60
40
20
Ft lbs
0
1
2
3
4
RPM/1000
Std. M151
MAHBE WOT

Figure V-31

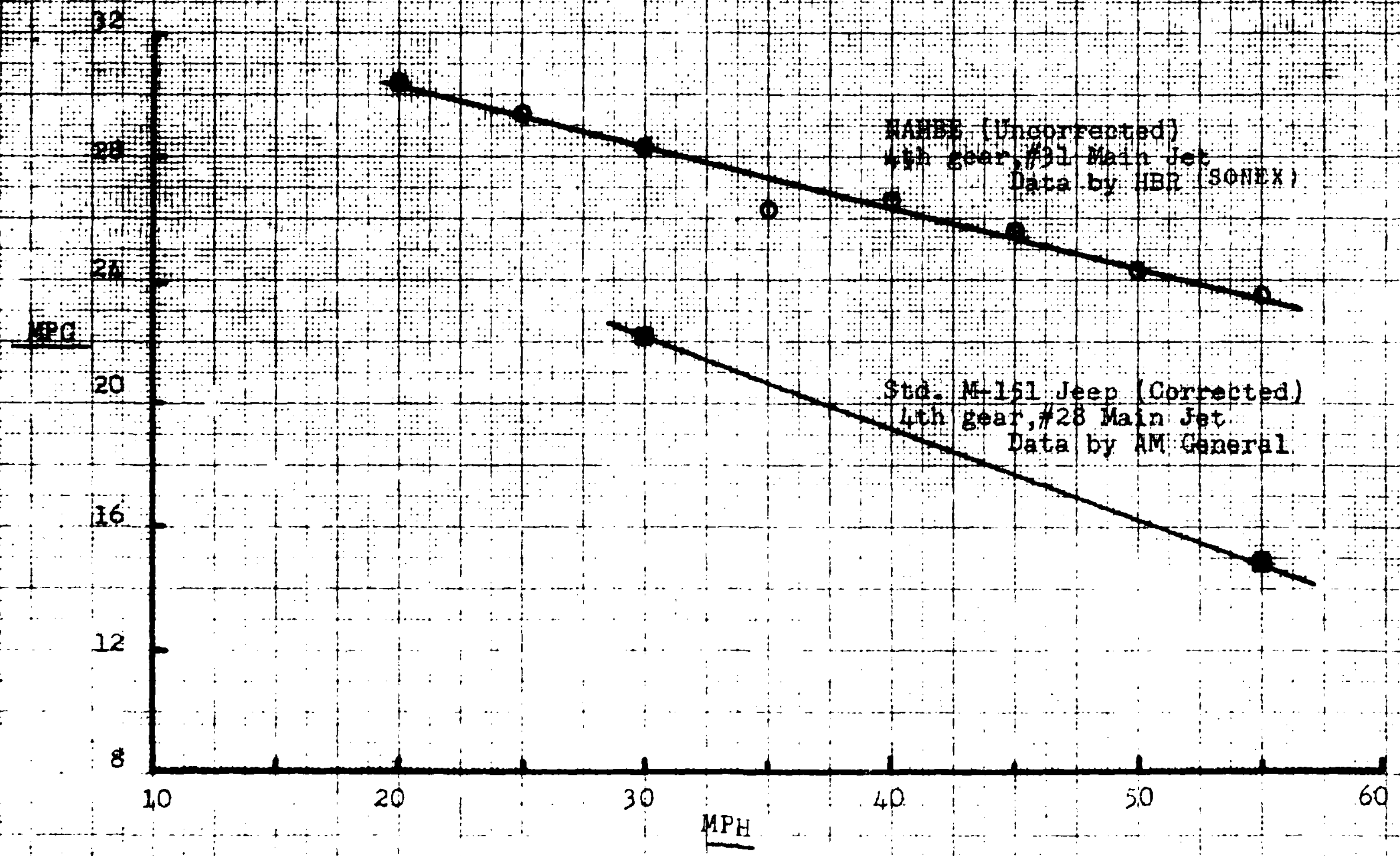

MPG
32
28
24
20
16
12
8
10
20
30
40
50
60
MPH
NAHBE (Uncorrected)
4th gear,#31 Main Jet
Data by HBR (SONEX)
Std. M-151 Jeep (Corrected)
4th gear,#28 Main Jet
Data by AM General

Figure V-32

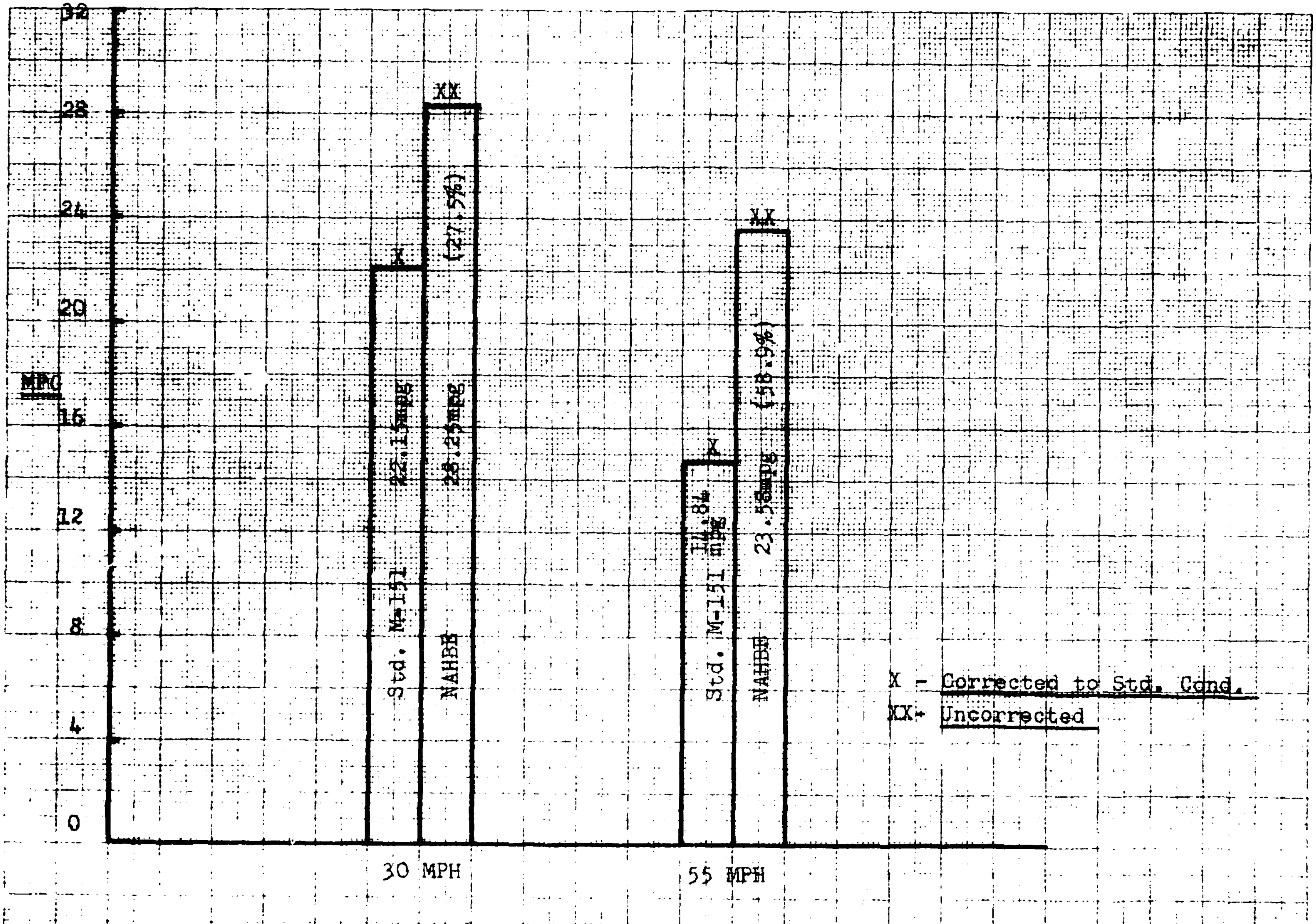

MPG
0
4
8
12
16
20
24
28
32
X
XX
Std. M-151 22.15mpg
NAHBE 28.25mpg (27.5%)
Std. M-151 mpg 14.84
NAHBE 23.58mpg (58.9%)
30 MPH
55 MPH
X - Corrected to Std. Cond.
XX - Uncorrected

Figure V-33

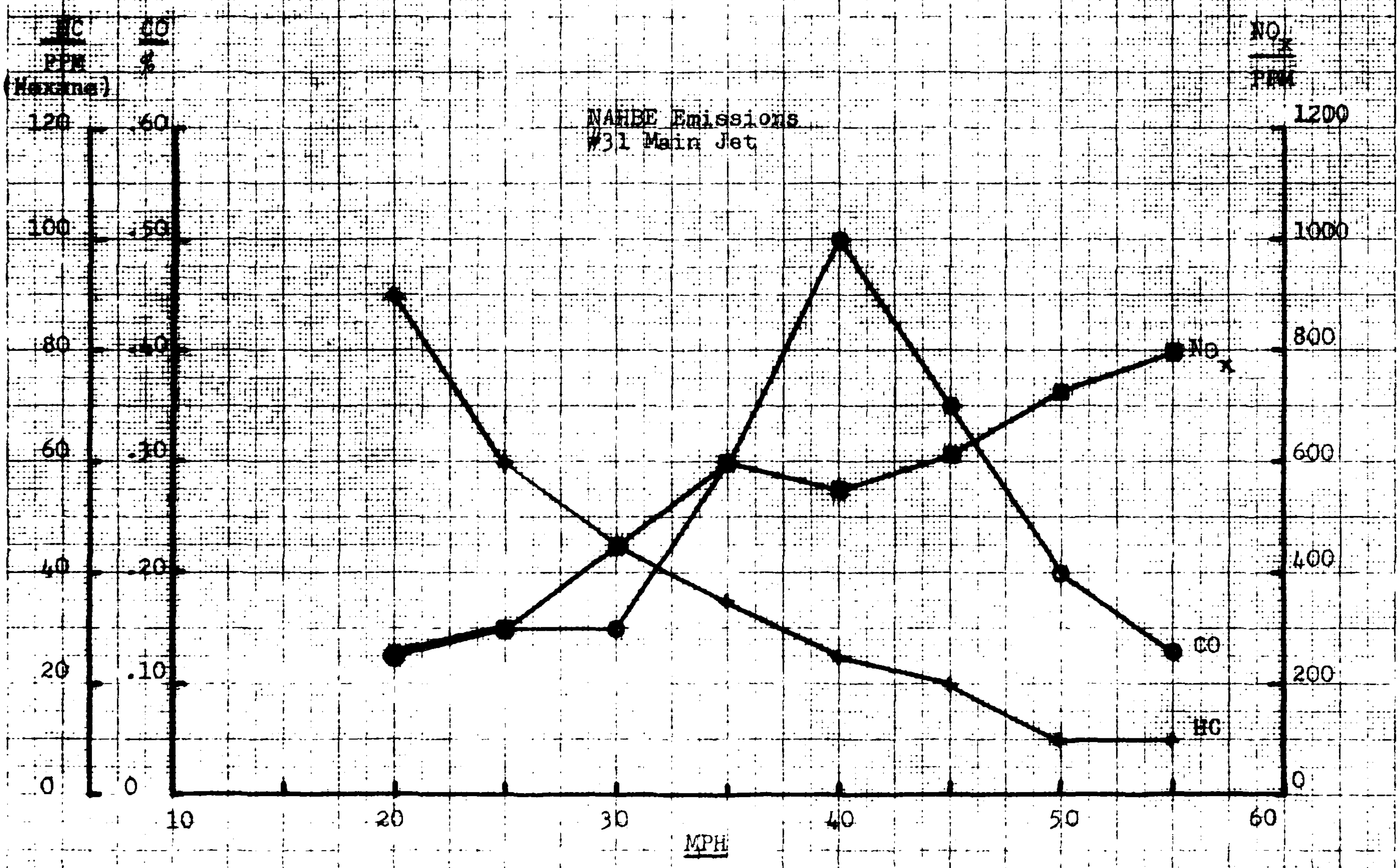
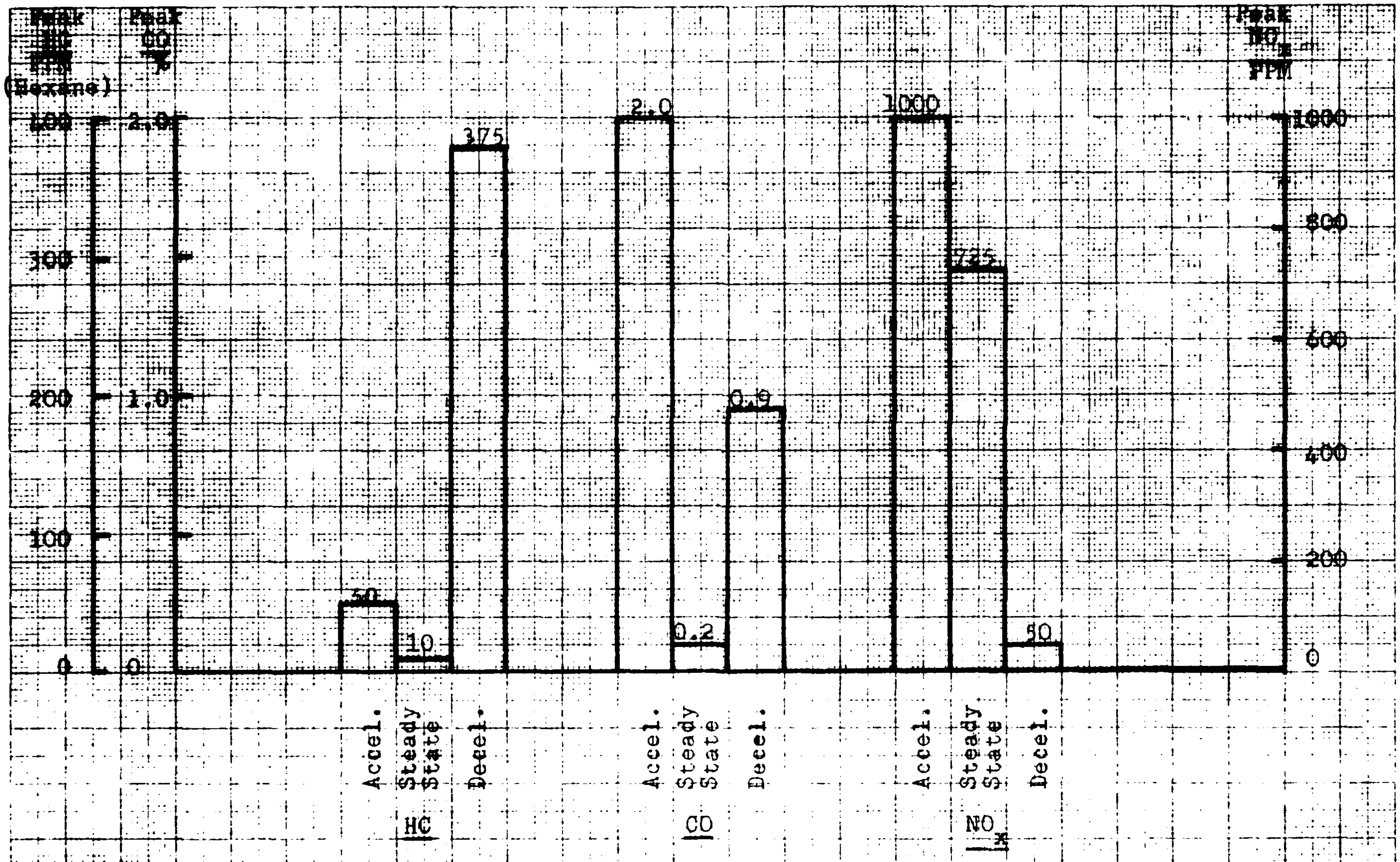

HC
PPM
(Hexane)
CO
%
NAHBE Emissions
#31 Main Jet
NO_x
PPM
120
100
80
60
40
20
0
.60
.50
.40
.30
.20
.10
0
1200
1000
800
600
400
200
0
NO_x
CO
HC
10
20
30
40
50
60
MPH

Figure V-34



Steady State And Peak Transient

NAHBE Emissions
#31 Main Jet
(Idle to 50 Mph to Idle)

Figure V-35

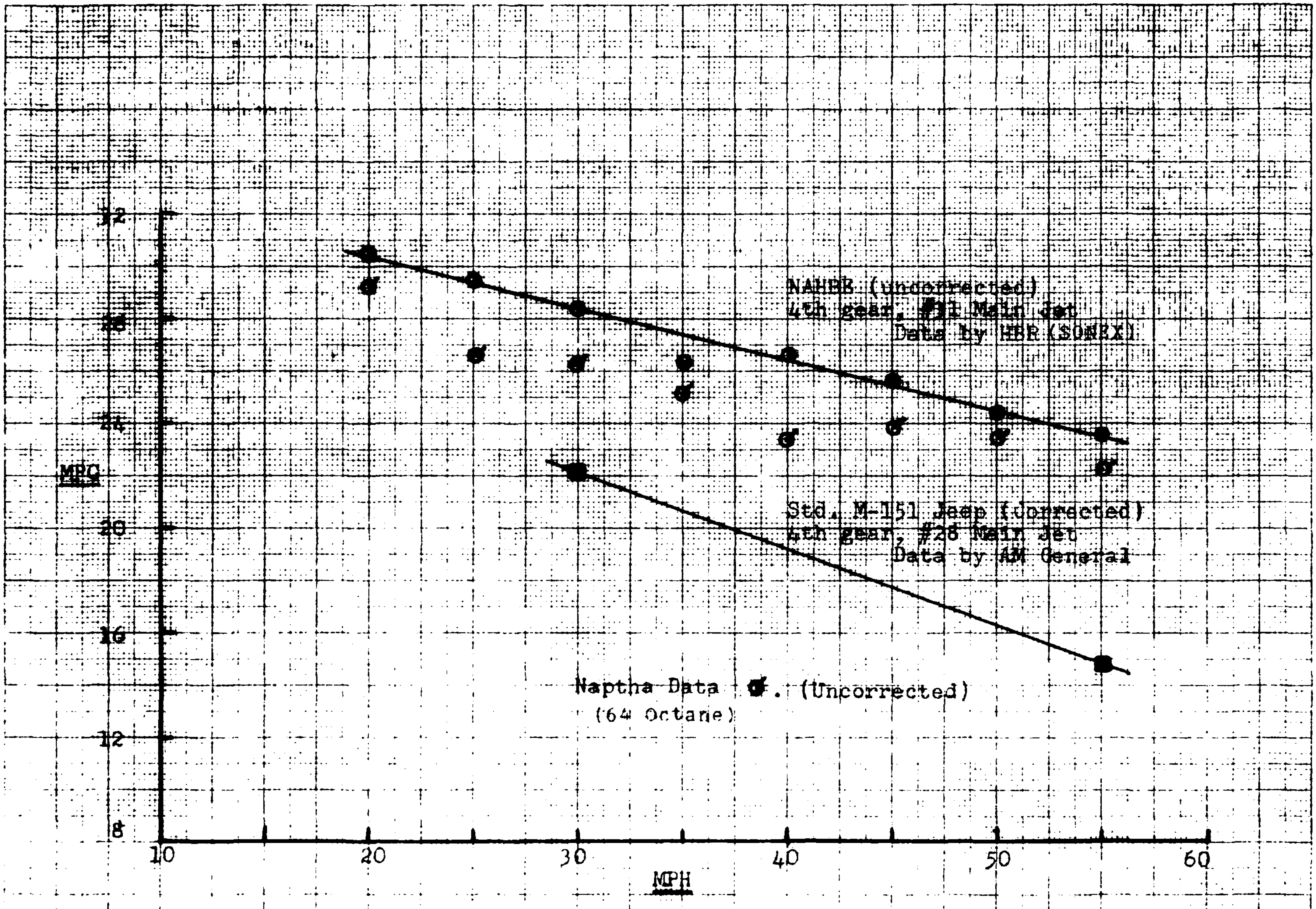

NAHBB (uncorrected)
4th gear, #31 Main Jet
Data by HBR (SONEX)
Std. M-151 Jeep (corrected)
4th gear, #28 Main Jet
Data by AM General
Naptha Data ♂. (Uncorrected)
(64 Octane)
MPG
32
28
24
20
16
12
8
10
20
30
40
50
60
MPH

Figure V-36

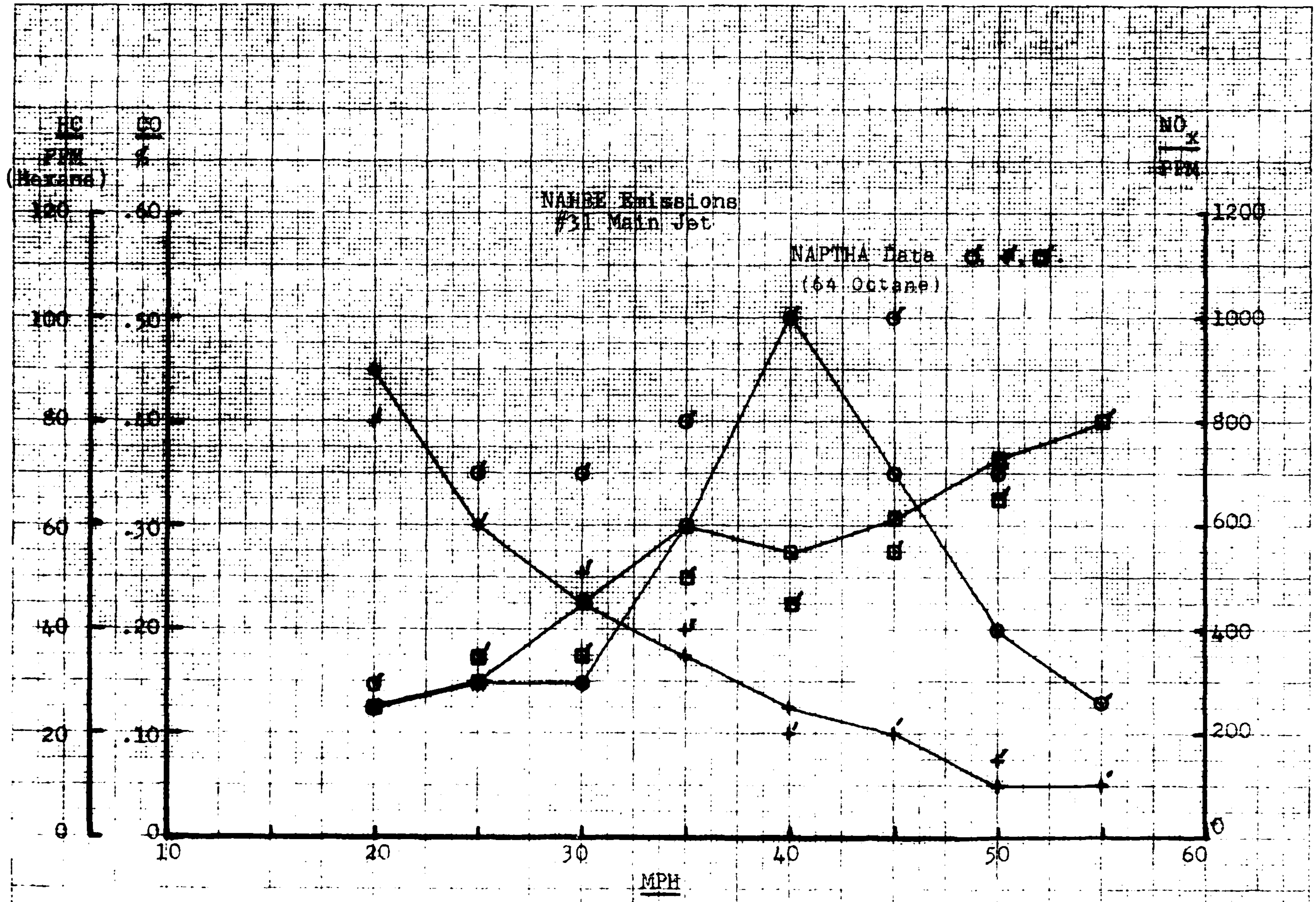
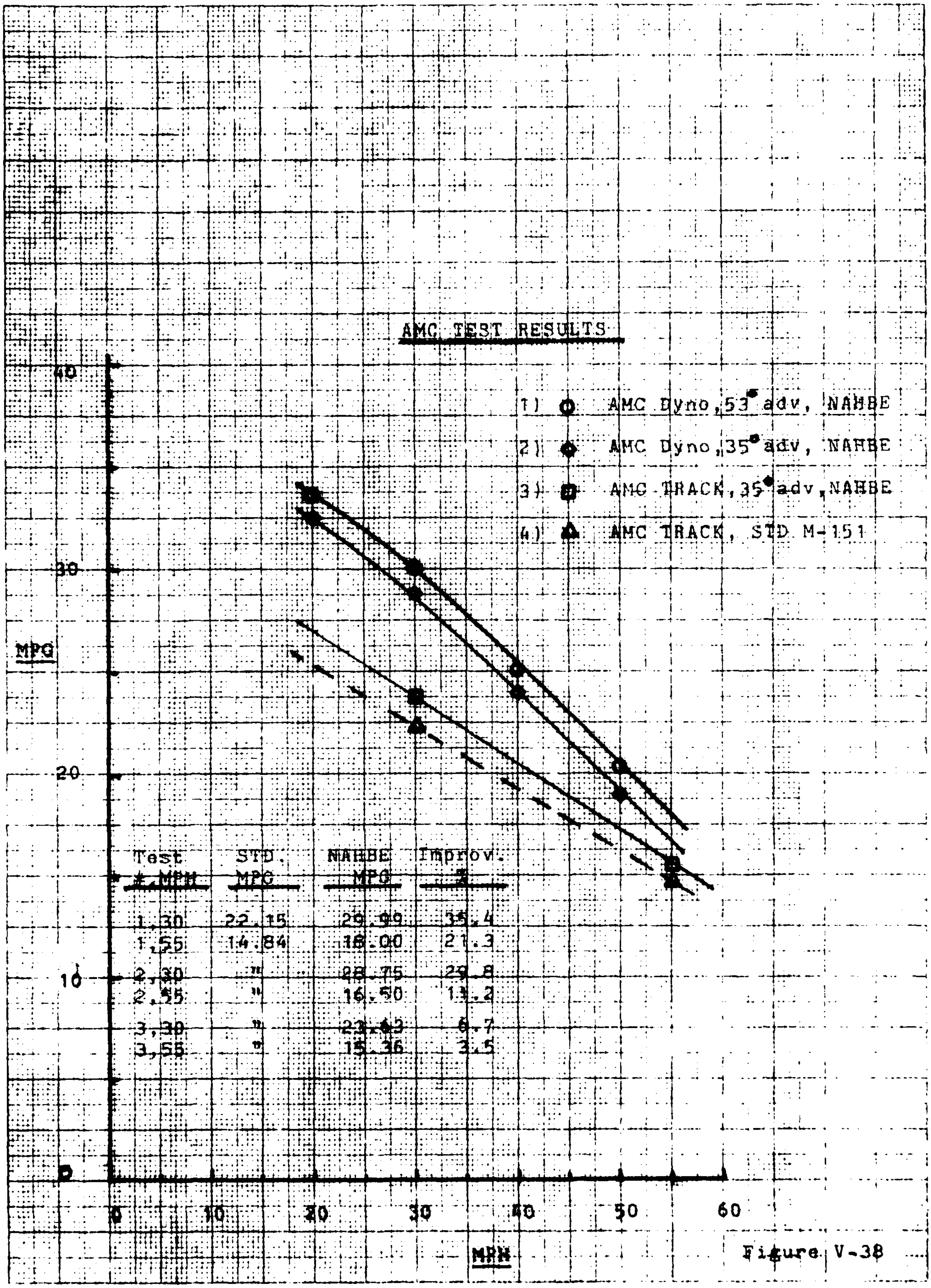

HC PPM (Hexane)
CO %
NO_x PPM
NAHBE Emissions
#31 Main Jet
NAPTHA Data
(64 Octane)
MPH
0
20
40
60
80
100
120
0
.10
.20
.30
.40
.50
.60
0
200
400
600
800
1000
1200
10
20
30
40
50
60

Figure V-37



Test #, MPH	STD. MPG	NAHBE MPG	Improv. %
1,30	22.15	29.99	35.4
1,55	14.84	18.00	21.3
2,30	"	28.75	29.8
2,55	"	16.50	11.2
3,30	"	23.63	6.7
3,55	"	15.36	3.5

Figure V-38

b) Test Procedure

The engine in each case was warmed up and test runs initiated when oil and water temperatures were stable. At fixed throttle the maximum load was applied that the engine would hold some minimum RPM. The load was then reduced at fixed throttle in 200 RPM increments. Exhaust gas temperature was taken at the exhaust manifold discharge. Emission samples were taken with the probe located approximately 5 feet downstream of exhaust manifold. The NO_x meter was not available at the time of these tests.

For the sake of easy comparison individual performance curves at 1/4 throttle through WOT for the NAHBE and standard M-151 engine are plotted in Figure V-1 through V-16; summary curves are given in Figures V-17 through V-27. With the manually operated dynamometer available, testing at 1/4, 1/2, 3/4, and WOT was the most reliable and repeating method. Standard SAE correction factors were used in calculating results.

c) Test Results

Comparing the horsepower output at 1/4 and 1/2 throttle, the NAHBE output exceed the standard M-151 output beyond the point where the standard curves break off. This also shows up in the later torque curves. At 3/4 and WOT the standard M-151 engine output exceeds the NAHBE for the reasons stated in the section on manifolding and carburetion. To show how output could be increased in the same engine a downdraft Holley two barrel carburetor was adapted to the intake manifold with the result shown in Figure V-19. Maximum output at maximum RPM exceeded the standard M-151

with an intake manifold that did not favor high engine output (secondary air flow was too low). The torque curves at WOT also reflect this in Figure V-31.

Part throttle torque curves of Figure V-28 show manual and automatic (FIDCO) secondary air control. As was pointed out earlier, torsional vibrations from the waterbrake impeller disturbed the electronic control so all waterbrake results are for manually adjusted secondary air. In the chassis dyno these results are inverted with automatic air control results exceeding manual results. Again at 1/4 and 1/2 throttle, at the shift point of about 3000 RPM, NAHBE torque exceeds the standard M-151;and even at 3/4 throttle there is no break to a lower torque at higher RPM. Although peak torque of the standard M-151 exceeded the NAHBE, it is possible there is less difference now that the engine is broken in; a gain of 10-15 psi in compression readings was experienced later in the chassis dynamometer testing.

Brake specific fuel consumption (BSFC) at 1/4 throttle is significantly lower in the NAHBE than the standard M-151. Comparing the average between the two, the decrease in average BSFC at 1/4 throttle is 44%. The improvement decreases, as expected with the design compromises made, with increasing throttle setting. The improvement decreases to 5.5% at WOT with "standard" carburetion and 9.3% using the Holley carburetor. It is significant to recall these results when comparing later results in the chassis dyno at 30 and 55 mph.

There is no significant difference in CO at 1/4 throttle; at 1/2 throttle a wide excursion from .1% to 7.0% occurs in this standard engine

under high load with low manifold vacuum. At 3/4 throttle, low load, high RPM conditions, NAHBE CO increases from 0.1% for the standard engine to 0.35%; at high load, low RPM, NAHBE CO is 0.5% while the standard engine is 1%. Below 3400 RPM all NAHBE CO readings are significantly lower. Again because of the design compromise at high throttle openings, the NAHBE CO readings are above those for the standard engine, Figure V-15.

Unburned hydrocarbons (HC) at 1/4 throttle are considerably lower in the modified engine at all but two RPM readings; the same can be said at 1/2 throttle. At 3/4 throttle NAHBE hydrocarbons are lower at RPM other than the one reading where they are equal. At WOT, even though fuel-air ratios are not optimum, the modified engine HC are lower over most of the load range, Figure V-16.

Exhaust gas temperature (EGT) for the two engines is compared in Figures V-26 and 27 at throttle settings from 1/4 to WOT. All NAHBE EGT's are lower than for the standard engine with the highest modified engine readings corresponding to the lowest standard engine readings. The average spread in readings at a given RPM is significantly lower for the NAHBE with a typical spread of $50^{o}F$ while the typical standard M-151 spread is $150^{o}F$.

This difference in exhaust temperatures is to be expected (Reference 1). It gives rise to an unexpected effect on the road, however. One sees the exhaust manifold and exhaust pipe flow "cherry red" back to the muffler in chassis dyno tests in the standard engine; thus, one has a very effective thermal reactor to reduce CO and HC emissions. This is not the case with the modified engine. It can be shown that a decrease in exhaust gas

temperature can reduce the exhaust gas reaction rate by a factor of 10.

3) Chassis Dynamometer Tests of NAHBE-M-151 by Sonex

A Clayton inertial wheel chassis dynamometer (installed at Sonex's facilities) was used to test the retrofitted M-151 Jeep under steady state and transient conditions. Fuel flow was measured with a Fluidyne Model 1226 meter with digital readout. Carbon monoxide (CO) and hydrocarbons (HC) were measured on a Beckman Model 590 Infrared n-Hexane Analyzer and NO_x was measured on a Thermo Electron Chemiluminescent Analyzer; all were recorded on a Linear Chart Recorder. Instrumentation was calibrated at the beginning of each run and span gas (from Scott Labs) checks were made periodically. Because of some uncertainty in the chassis dyno calibration, road load was set to match actual manifold vacuum observed at 50 mph on the road.

Testing

All steady state testing was conducted at stable engine coolant temperatures with speed maintained constant by a driver. Data were recorded for a three-minute period. The results presented here are the best compromise of manifolding, secondary air control (FIDCO), carburetor jetting, valve clearance, and spark timing. All these parameters were optimized in the waterbrake dyno but adjusted further according to the chassis dyno test results.

a) Steady State Test Results (Regular Gasoline)

Miles per gallon

Figure V-32 compares the modified M-151 as delivered by Sonex to AM General with the base line data at 30 and 55 mph provided by AMG.

Our chassis data is based on observed or uncorrected results while AMG data has been corrected to standard conditions. For the atmospheric conditions at the time, correction to standard conditions would further increase the NAHBE miles per gallon. Since it is uncertain that our dyno loads are equivalent to the AMG loads, the data were left uncorrected.

The improvement in mpg at 30 mph is 27.5% and 58.9% at 55 mph as seen in Figure V-33. According to the part throttle results obtained in the waterbrake dyno, further chassis dyno improvement should be possible at the lower speeds since the average improvement at 1/4 throttle was 44%.

Emissions

Steady state emissions are given for the final configuration in Figure V-34. Comparable emissions for the standard M-151 are not available, however, some additional tests for mileage and emission are compared by AMG in the next section.

The excursion for CO from the .1% level at 30 mph to .5% at 40 mph and returning to the .1% level at 55 mph is due to a mismatch in secondary air control. The manifold vacuum shows a similar excursion increasing to 14 in. Hg at 40 mph from 13 in. Hg at 30 mph, then decreasing to 11 in. Hg at 50 mph. The FIDCO air controller drove nearly closed at 40 mph thus limiting the flow of secondary air. With proper tuning of the unit it should be possible to run all steady state conditions from 20 to 55 mph at 0.10-0.20% CO.

Transient test results - acceleration and deceleration

The test results in the waterbrake dyno showed consistently smooth curves with no marked departures at any throttle settings. However,

when the engine was placed in the vehicle and given base line CVS-3 tests in a chassis dyno at Scott Labs prior to the installation of the HBR chassis dyno, recordings of transient operation showed high CO under acceleration and deceleration. In tracing down the source it was found that the carburetor modification by HBR (insertion of a boost venturi) caused an overly rich condition from 20 to 25 miles per hour only.

Thus, the carburetor was returned to stock conditions, except for jet size and power valve spring. The main jet was increased to a #32 and washers inserted under the power valve spring to actuate it at about 5 inches of Hg (from tests at FACIT, manufacturers of the carburetor).

To further improve the accel-decel emissions various combinations of gulp valves, throttle dash pots and high idle throttle solenoid actuated by a vacuum switch were investigated. It is possible that the latter modification can be used if the orifice in the vacuum valve is modified, but the simplest solution was to use the dash pot plus slightly higher idle. (The engine will idle down to 200 RPM.)

The values of peak emissions recorded for steady state and transient conditions are shown in Figure V-35. Testing was conducted from idle to 50 mph back to idle with a normal shift schedule and in-gear decel with no accelerator pressure on decel. The relatively high decel CO and HC appear after several seconds on passing through 20-25 mph. This would be considered a severe decel.

b) Steady State Test Results (Naptha or Broadcut Fuel)

A sample of "naptha" or broadcut fuel (flash point 70°F, Octane Rating*64MON was used in the modified M-151 in the chassis dyno to show the

*Courtesy Maryland State Fuels Testing Lab, Jessup, Maryland

engine's insensitivity to octane rating. With no changes in engine adjustments, the data in Figures V-36 and V-37 was taken in the same manner as before and plotted as observed, or uncorrected data. No knock was heard during the test, idle was normal, engine starting and response were normal.

It is believed that these results can be further improved since a previous test with a V-8 engine using the same fuel sample a year earlier showed an improvement of 10% over regular gasoline. A recheck on all engine settings showed that performance could be improved with regular gasoline by increasing the main fuel jet.

During the check mentioned above compression tests showed a change in operating conditions. This change in engine conditions came about after the head was removed and the valve seals replaced. Oil leakage through the seals was noted on decel so the seals were replaced and the deposits removed from all surfaces. With the deposits removed, spark could be advanced 4 degrees and the main fuel jet increased in size to #32. Best overall performance was attained with these final settings, but no "naptha" was available for further testing.

4) Baseline and NAHBE Chassis Dynamometer and Road Tests of the M151 Vehicle by AM General

An M151/A2 vehicle (10#151-90988) was tested and shipped to Sonex on 20 October 1981. Driveability, power checks, 4K mileage accumulation, CVS tests, fuel economy tests and noise test results were delivered to Sonex by AM General and some of the raw data are shown in Appendix A.

The same engine tested above was retrofitted by Sonex as described earlier and approximately 4K miles were put on the engine in the above vehicle both on the road and in chassis dynamometer as

described in the previous section. The vehicle was then returned to AM General to repeat the tests of the baseline.

At this point, however, the auto industry, including AM General, suffered a severe crisis and not all testing was completed for reasons beyond the control of Sonex. It should be noted, however, that no funding for AM General by the government was involved in this project.

Both of the authors of this report did have an opportunity to work with the AMC dynamometer facilities and personnel for two days to calibrate the fuel and air delivery systems at the AM General load ratings used in the base line testing. AMC Amtek cell #5 was used.

Previous data show best power should be attained at an air/fuel ratio of about 16:1. Thus, to obtain this air/fuel ratio during the vehicle acceleration schedule of the CVS3-Hot 505 test the power/acceleration jet was reduced from a stock diameter of .052 inches to .016 inches, a decrease of 90% in flow cross section of the jet. Response improved as the jet size was reduced. Main fuel jet size was set at #31 giving steady state air/fuel ratios of about 18:1 while 20:1 was desirable. Idle air/fuel ratio varied from 20.5 to 22.7 in the Hot 505 test, but a maximum of 23.6 was achieved at about 350 RPM in other tests.

These results were necessarily a compromise from ideal conditions since the spark was retarded from near MBT conditions of 53^{o} to 35^{o} (at 30 MPH) since no vacuum advance system is used in the M151. Over advance conditions would have resulted on acceleration with the 53^{o} advance. The results with both spark settings are given in Figure V-38.

The best mileage at 50 MPH of 22 MPG occurred in the AMC tests with a spark advance of 13^{o}, air/fuel ratio of 17 and about 25% choke. This

would have indicated an unbalance existed in the fuel and air delivery system,which is quite possible in this exploratory stage of development.

The vehicle was next tested by AMC personnel on the track without the benefit of Sonex personnel present. There is no assurance, therefore, that all systems were operating properly in the AMC track results given in Figure V-38. The marked difference between dyno and track results, essentially at the same manifold pressure, would indicate that the air delivery system was off or not functioning properly.

One further track test was conducted without Sonex personnel present. These results for the SAE track test are given in Table V-1 for the stock and modified M151 with the percent improvement noted.

TABLE V-1
AM General Comparison for Stock and
NAHBE M-151 Vehicle, SAE Track Test

Test	Stock MPG	NAHBE MPG	Improvement %
City	15.18	16.32	7.5
Suburban	17.39	18.79	8.1
Highway	16.07	17.76	10.5
30 MPH	22.15	23.63	6.7
55 MPH	14.84	15.36	3.5

VI. RESULTS AND CONCLUSIONS

1. Sonex water brake test comparisons between a stock M151 engine and a retrofitted NAHBE version showed significant improvement in fuel economy at part throttle conditions as well as in harmful emissions. The air delivery system was controlled manually in these tests.
2. The flatter torque curve allowed higher torque at high RPM, while the peak torque was slightly lower.
3. At wide open throttle (WOT) the pressure drop through the air delivery system prevented supplying sufficient secondary air to operate at required 16:1 air/fuel ratios. The torque was therefore slightly less than stock. With a shift in carburetion to a two barrel carburetor allowing more control in the fuel delivery, the torque at high RPM exceeded stock torque with lower specific fuel consumption.
4. Stable idle below 400 RPM at air/fuel ratios from 22:1 to 23.6:1 with low emissions and good torque were possible. Fuel consumption at idle was reduced from about 6 lbs per hour to about 2 lbs per hour.
5. The results obtained with a retrofitted multi-cylinder engine indicate that many of the trends observed in a single cylinder CFR engine can be obtained under part throttle multi-cylinder operation. As WOT conditions are approached control of secondary air is decreased due to the shift in manifold vacuum and the decrease in stratification that results.

6. Knock free operation with 64 octane fuel confirmed earlier M151 tests with a variety of fuels. Carbureted compression ignition tests were not attempted in this study.
7. At a cost to the government of less than $10K, with a crude NAHBE version of Sonex technology it was demonstrated that the stated objectives could be met, namely:
   a. an on-the-road prototype developed which would improve fuel economy.
   b. emissions lowered (steady state only were documented) using no EGR, no exhaust air pump and no catalytic converter.
   c. the engine would be insensitive to Octane number.
   d. the design would be retrofitable.

VII. RECOMMENDATIONS

1. To fully take advantage of these and other laboratory tests to date that indicate:

   a. increase in fuel economy

   b. octane insensitivity

   c. multi-fuel capability

   d. low compression ratio (<8:1) compression ignition capability

   e. appreciably lower exhaust system temperatures,

a serious development program should be implemented to determine how best to use these attributes in military vehicles.

VIII. REFERENCES

1. Pouring, A. A., Failla, C. C., Rankin, B. H., Keating, E. L. and Riddell, F., Parametric Variations of a Heat Balanced Engine, Fluid Mechanics of Combustion Systems, ASME, June 1981.

2. Allen, J., Pouring, A. A., and Keating, E. L., Heat Balanced I.C. Engine Transition Studies, AIAA-82-1116, June 1982.

3. Keating, E. L. and Pouring, A. A., Internal Regenerative Air Standard I.C. Engine Cycle Performance, AIAA-82-1281, June 1982.

4. Pouring, A. A. and Rankin, B. H., Time Dependent Analytical and Optical Studies of Heat Balanced Internal Combustion Engine Flow Fields, AIAA-82-1283, June 1982.

5. Leshner, M. D., Stuart, Jr., J. W., and Leshner, I., Closed Loop Control for Adaptive Lean Limit Operation, SAE-780039, February 1978.

6. Noguchi, M., Tanaka, Y., Tanaka, T., and Takeuchi, Y., A Study on Gasoline Engine Combustion by Observation of Intermediate Reactive Products During Combustion. SAE-790840, Sept. 1979.

APPENDIX A

AM GENERAL BASELINE TEST RESULTS

HK8

Prepared By: D. SUTHERLAND **DETROIT RESEARCH REPORT** Report No. ____

Page No. 1 OF 3

AMERICAN MOTORS CORPORATION

Approved By: ____ Date OCTOBER 9, 1981

TRACK ROUTE FUEL ECONOMY & PERFORMANCE

Subject: A.M. General, M151, 4 Cylinder - 141.5 CID, Manual 4/Speed Transmission, with 7.00x16 tires.

VEHICLE DESCRIPTION	
Lab Number	M151
Make and Model	A.M. General - M151
Engine	4 Cylinder - 141.5 CID
Carburetor Type	Zenith 13660
Transmission	Manual 4/Speed
Axle Ratio	
Tire Size	7.00x16
Special Components and Comments	Baseline
Curb Weight	2360 lbs.
Test Weight	2660 lbs.
Odometer	4,027.2 miles
Driver	S. Watts
CONDITIONS	
Temperature °F.	46°F
Wind MPH	120° (ESE) @ 5 mph
Humidity %	76%
Barometric Pressure in. Hg	30.26 in. Hg
PERFORMANCE	
0-60 MPH	25.8 seconds
Standing ¼ Mile	21.3 seconds @ 56.7 mph
FUEL ECONOMY * Comments:	
4 CYCLE AVERAGE (MPG)	15.87
CITY CYCLE (MPG)	15.18
SUBURBAN CYCLE (MPG)	17.39
HIGHWAY CYCLE (MPG)	16.07
55 MPH INTERSTATE CYCLE (MPG)	14.83

Pre-released data

RECEIVED
ENGINEERING
AMG/AMTEK

CONSTANT THROTTLE FUEL ECONOMY	30 MPH	55 MPH	70 MPH
MPG @ Manifold Vaccuum	22.15 MPG @ 11.02 in. Hg	14.84 MPG @ 3.18 in. Hg	------

* Corrected to 60 Ambient Temperature, 60 Fuel Temperature, 0.7370 Fuel Specific Gravity, and 29.00 in. Hg Barometric Pressure.

** Emission Dynamometer Fuel Economy [illegible] Estimates Based on Correlation with [illegible] Emission Dynamometer and made with [illegible] Confidence.

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PREPARED BY: D. Sutherland

DETROIT RESEARCH REPORT

AMERICAN MOTORS CORPORATION

REPORT NO.

PAGE NO 3 of 3

APPROVED BY:

DATE October 9, 1981

SUBJECT: WOT ACCELERATION

CAR MAKE A.M. General YEAR 1982 MODEL M151 LAB NO M151

ENGINE NO ENG TYPE, DISPL 4 Cylinder - 141.5 CID

SERIAL NO D151 90988 CARB Zenith 13660 TRANS Manual 4/Speed

AXLE RATIO TIRE SIZE 7.00x16 ROAD FACTOR

TEST WT 2660 lbs. ODOMETER 4,027.2 miles

WEATHER: TEMP 52 °F WIND NE @ 6 MPH HUMID 62%

TEST COURSE MIS DRIVER S. Watts OBSERVER ---

SPECIAL COMPONENTS, COMMENTS

Baseline

DATE OF TEST 10/9/81

TIME 0-60 MPH 25.8 SEC

STANDING ¼ MILE

21.3 SEC TO 56.7 MPH

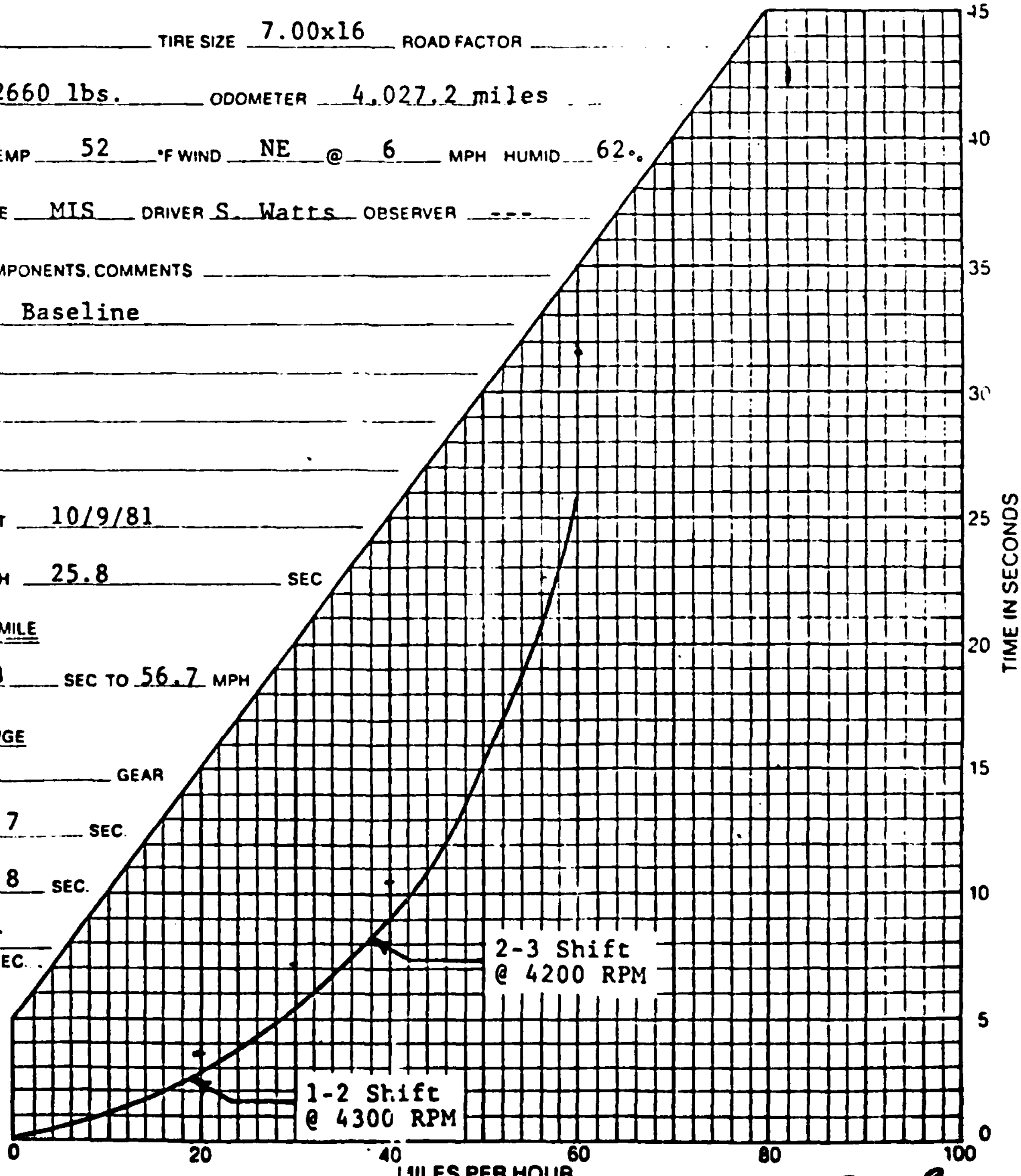
PASSING RANGE

Thru GEAR

30-50 9.7 SEC.

40-60 16.8 SEC.

50-70 - SEC.



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DETROIT RESEARCH REPORT

AMERICAN MOTORS CORPORATION
TRACK ROUTE DRIVING CYCLE
FUEL ECONOMY

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